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ECONOMIC BOTANY

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VOL. 7 JANUARY–MARCH, 1953 No. 1

Semi-Popular Articles

Utilization Abstracts

Book Reviews

Barley—*Botany, Production, Harvesting, Processing, Utilization and Economics*

Barley, probably the oldest cultivated cereal, is widely grown in cooler areas of the world. The annual world production of nearly two and a half billion bushels exceeds that of rye but is less than that of rice, wheat, corn and oats, respectively. Most of the annual 300 million dollar crop of the U.S. is fed to livestock, but about one-third is manufactured into malt.

H. L. SHANDS[1] AND A. D. DICKSON[2]

Introduction

Barley is one of the important cereal members of the grass family. The grain is used largely for animal feed, although appreciable quantities are utilized for malting purposes and human food. There is great diversity in the use of the processed malt. Barley, an annual crop having winter and spring varieties, thrives best in cool weather. The grain is produced in spikes or heads at the tops of plants that are about 30 inches tall. The individual kernels usually weigh about 30 milligrams. Fruiting time and maturation differ between varieties. The shape, color and other markings of spikes (heads) and kernels offer many large and small differences so that a large number of possible combinations occurs.

Distribution

Barley grows in nearly all temperate regions of the world as well as in hotter

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and drier areas, such as Asia Minor, North Africa and other Mediterranean areas. Barley is the most widely distributed of cereal crops, probably more so than any other cultivated crop. The extreme northern limits of cultivation lie near the Arctic Circle, and yet it is found growing within 17½ degrees of the equator, according to Harlan and Martini (10). There are spring types that mature in as short a period as 60 to 70 days, while the winter types may require as long as 180 days. Barley is found growing in high altitudes on all continents. The crop is not particularly winterhardy, nor is it favored by hot humid weather. Barley is thought to be more tolerant of alkali than other cereal crops. It is best adapted to fertile soils.

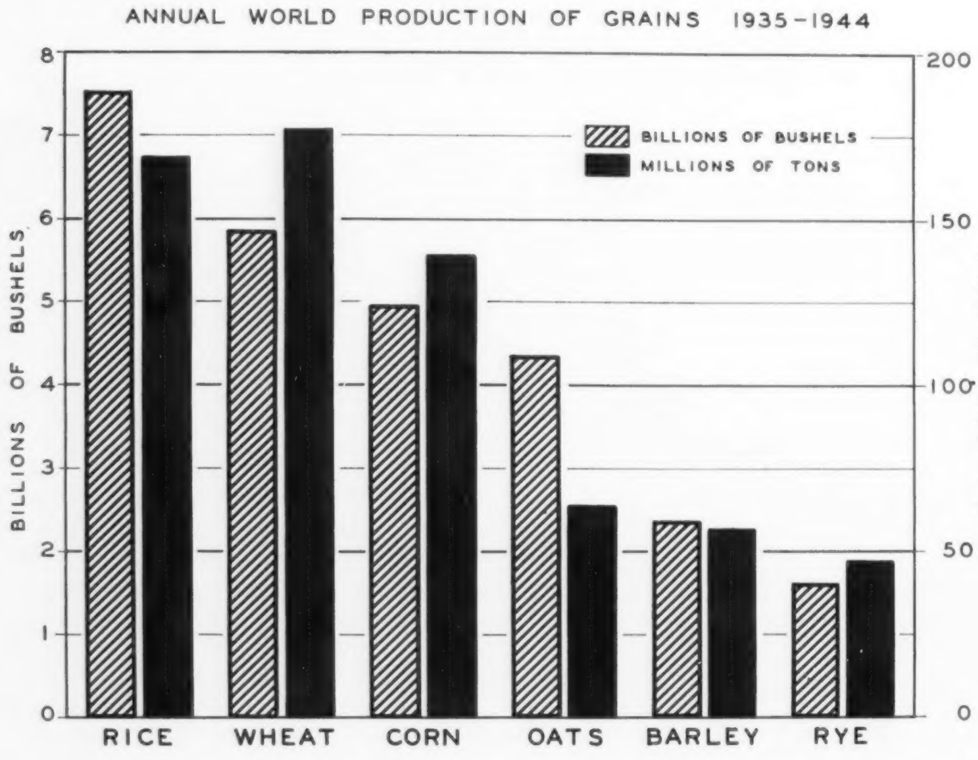


FIG. 1. Annual world production of cereal grain crops in billions of bushels and millions of tons. Average 1935–1944. Wheat leads in tonnage and is followed in order by rice, corn, barley and rye.

Production in the United States is heaviest in the north central States and California, but the crop is grown over most of the other sections of the United States with lesser amounts in the Southwest, the extreme Southeast and the humid areas of the southeastern States. One of the reasons for barley being limited in production in the last named area is the prevalence of such diseases as leaf rust and mildew which seriously reduce productivity of the plant.

Types

Spring Barleys. The common nodding six-rowed type of barley is variable as to color of mature plant parts, size and strength of straw, height of plants, and character of awns. Common barley is

widely distributed in Russia, Syria, Asia Minor, Manchuria, Turkestan, Europe and United States. The six-rowed types prevail in South America but production is generally small. There are erect six-rowed types in southern Europe, the Alpine regions, the Mediterranean area, eastern Asia and Japan. Some of the six-rowed erect types are grown in Great Britain and western Europe. However, the two-rowed types are dominant in England, Central Europe, Scandinavia and some of the Rocky Mountain sections and western areas of the United States. There is a less common two-rowed type, the *deficiens* type, in Abyssinia and Arabia.

FIG. 2. (A) *Hordeum vulgare,* the most commonly grown six-rowed barley. (B) Intermedium representative of *H. vulgare*. Lateral kernels are much reduced in size.

In the heavier producing areas of the

United States and Canada, common six-rowed barleys outyield the two-rowed types. Usually the two-rowed barleys produce about five bushels less per acre in the Upper Mississippi Valley. There are limited areas in eastern as well as western United States, however, where two-rowed barleys outyield six-rowed types.

The most important areas of spring barley production in the United States are in the North Central States, including North Dakota, Minnesota, South Dakota, Wisconsin, Michigan and Illinois, and in northern New York. Six-rowed spring barley predominates in Canada. Semi-winter types are found growing in China, Korea and Japan, and in the winter barley sections of the United States.

Winter Barleys. The winter barley area of the United States is south of a line extending from New York southwestward through the southern parts of Pennsylvania, Ohio, Indiana and Illinois, then through the central part of Missouri and Kansas to northern Texas. The true winter types, though less hardy than wheat, are grown in this area. Still farther south typical spring barleys can be grown as well as the semi-winter group. Winter barley is grown also in Korea, China, Kashmir, Transcaucasia, Europe, and to a limited extent in Canada. When barley exhibits a strong tendency toward the winter type, there is a possibility of using it for pasture purposes.

Another area of barley production is in California where North African type varieties are grown. These varieties are typically spring in habit, although sown in November or December and harvested in early summer. They are large kerneled and are favored in the European markets for malting because the biochemical composition is similar to that of the European-grown two-rowed barleys. The California barleys have bright colored thick hulls that aid in the filtration step of the brewing process when used with two-rowed barleys.

Hulled and Hulless Grains. Most of the varieties of barley grown in the Occident have hulls that are attached to the caryopsis (seed grain). Others thresh free of the enclosing lemma and palea. These are known as "naked barleys" and are used for human food in some of the Asiatic countries.

Botany

Origin. Beaven reproduced a photograph of common six-rowed barley found in straw-lined pits in the Fayum about 60 miles southwest of Cairo. The grain is believed to have been placed there more than 5,000 years ago. Brücher and Åberg (5) pointed out that there are two major gene centers of barley. One is in Abyssinia where many kinds grow naturally without cultivation, and the other in the highlands of Sikkim and southern Tibet, now thought to be more important as one point of origin of cultivated barleys than was earlier believed. It is easy to assume that barley could have originated at either of these centers. On the other hand, it is possible that barley originated at some other location and gravitated to these two geographic areas.

Carleton (6) believed that *Hordeum spontaneum* C. Koch may have been the forerunner of all cultivated barleys. *H. spontaneum* readily crosses with cultivated species and produces fertile flowers, indicating complete compatibility. Therefore it is likely that chromosome structure and gene loci for the cultivated groups are similar to those for *H. spontaneum* and *H. agriocrithon* E. Åberg. Further, the same disease-producing organisms attack *H. spontaneum* and cultivated varieties. Sometimes the rachilla (brush at the base of the kernel) produces a fertile flower with a further suggestion that the rachilla may continue to extend itself to produce still

FIG. 3. (A, B) *Hordeum distichum.* (A) Common two-rowed barley with lateral florets present, but not bearing seed. (B) The deficiens type formerly known as *H. deficiens;* lateral floret structures are almost absent or deficient. (C) *Hordeum irregulare.* This barley resembles the deficient two-rowed barley except that it occasionally produces full-sized seed in the lateral flowers.

more fertile seed. This anatomic deviation might indicate an expanding spike and spikelet, suggesting that many-flowered forms may yet be developed. This fertile rachilla condition has been observed within *H. vulgare* L. emend. Lam.

Åberg (1) suggests that present day barley may have developed through a series of reductions in flower parts along the following lines: the panicle type of inflorescence to a spike (head), multiple spikelets at the rachis nodes to a single spikelet, several flowers in a spikelet to one, and a brittle to a non-shattering rachis. This theory presupposes that the two-rowed species were the derived forms and that the six-rowed sorts were earlier in origin. Åberg (1) also points out that common six-rowed barleys might have originated from *H. agriocrithon* or from a similar kind. The above explanations do not completely satisfy the authors as to the origin of barley. Perhaps work with proper intergeneric hybrids might unravel the uncertainties concerning the manner of origin of present day barleys.

Barley represents a polyploid series somewhat like wheat and oats. All common six-rowed and two-rowed barleys used in commercial production have 14 diploid chromosomes. It will be recalled that common wheats and oats have 42 diploid chromosomes, making barley a contrast in this matter. The major part of wheat and oat production is from 42-chromosome species, although there is minor production in 28- and 14-chromosome species.

Non-cultivated Barleys. There are several species of wild barleys that have 14 diploid chromosomes. They are *H. spontaneum, H. agriocrithon, H. maritinum* With. and others. Tetraploid barleys having 28 chromosomes are *H. jubatum* L., *H. murinum* L., *H. bulbosum* L. and others. There are many reports of 14 and 28 diploid chromosomes of *Hordeum,* but Smith (14) cites only one worker who reported 42 chromosomes in *H. nodosum* L., while several other workers reported only 28 for this species. There is doubt that the highest number given for *H. nodosum* is correct.

Cultivated Species. The cultivated barleys have been rearranged recently into three species by Åberg and Wiebe (2). The common six-rowed barleys are called *H. vulgare* L., while the two-rowed barleys are called *H. distichum* L. emend. Lam., and the irregular barleys are referred to as *H. irregulare* Åberg and Wiebe.

H. vulgare has three fertile flowers at each node of the rachis. In this species the lateral kernels are only slightly smaller than the median kernels. There is a second group of *H. vulgare,* called the intermedium group, in which the lateral kernels are appreciably smaller than the median ones. The two groups overlap, as there is a gradual change from one to the other.

Two-rowed barley with a non-shattering rachis is called *H. distichum.* Only the median florets are fertile. The much reduced lateral florets are usually sterile but occasionally produce a few seeds in the field or in the greenhouse. This group is divided into the typical two-rowed groups, where the lateral florets are very small, and the *deficiens* group, where the lateral florets are still smaller until there are practically no parts remaining. There is an intergradation between the two sub-divisions.

H. irregulare is the name given to a newly defined species of barley. The median florets are fertile, while the proportion of fertile and wanting lateral florets varies considerably. Inasmuch as irregular barleys are found in Abyssinia, it is likely that they originated there. Previous barley workers have referred to this group of "Abyssinian intermediate" barleys.

Classification. Several growth and structural characters of barley are relatively reliable in classifying and identi-

fying agricultural varieties. The growth habits of spring or winter, hairiness of leaf sheaths, collar shape at the node beneath the spike, as well as spike and kernel characters are considered by Åberg and Wiebe (3) as relatively constant for identification purposes. Grain color of cultivated varieties in the United States and Canada is either white or blue.

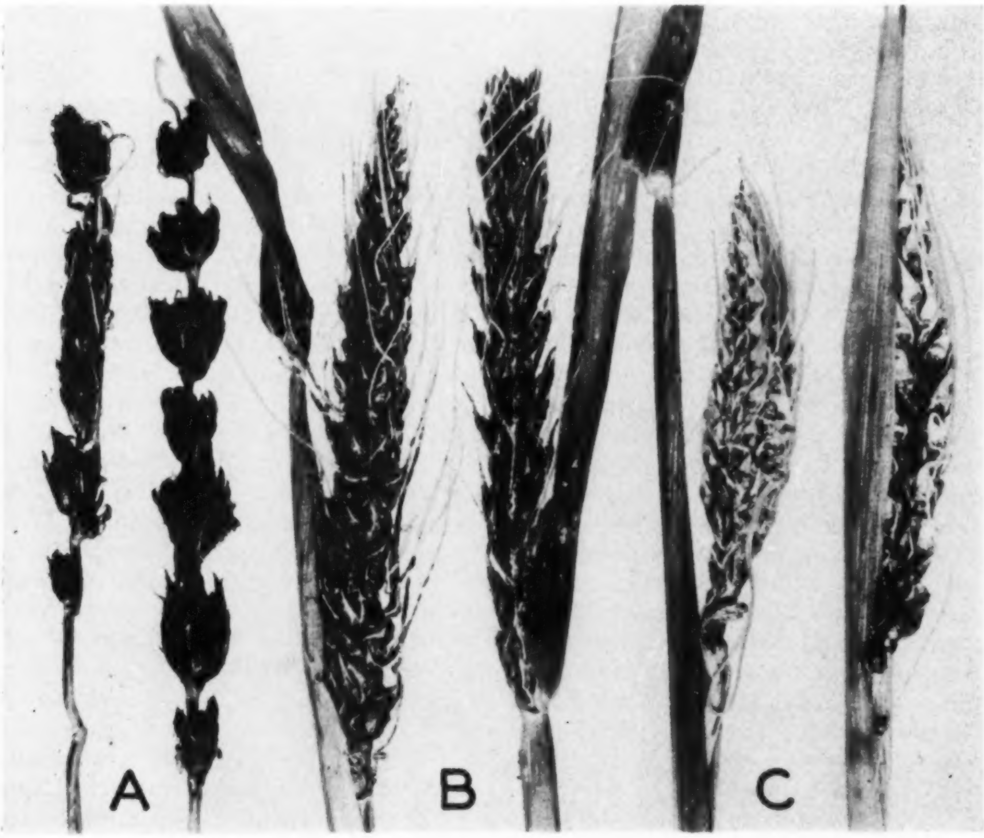


FIG. 4. Three smut diseases of barley where floral structures are largely replaced by smut spores: (A) True loose smut is controlled only by hot-water treatment of seeds; a few varieties are resistant. (B) Intermediate loose smut looks like loose smut but infects like covered smut; controlled by treating seed with proper fungicide. (C) Covered smut. Smut masses remain attached to rachis until harvest or combining; seed treatment is effective for control.

Certain of the spike characters are relatively reliable and remain almost constant under most conditions. The number of rows of kernels on the head, the length of rachis internode, the brittleness of the rachis, the hairiness of the rachis edge, and the glumes, glume-awn length, and barbing of the glumes are all used in classifying agricultural varieties. The stigma hairiness is a relatively constant character, but this can be used only when the plants are growing. Varieties differ in the presence and degree of barbing on the several lemma veins. There are hooded barleys that have no awns but instead have three-pronged appendages that remain rather close to the kernel and do not extend as in the case of the awn.

It is customary to purchase barley on the basis of a threshed sample. There are markings on the lemma and palea of

the kernel that materially aid in varietal identification. Some kernels have the lemma and palea attached and cemented to the caryopsis (the kernel), while others are hulless, or naked. Kernel length and shape are relatively constant characters, although they are influenced by plumpness of the grain. The filling and plumpness of the kernel depend a great deal upon the environmental conditions during maturation. At the base of the palea is a small brush called the " rachilla " on which are hairs of various lengths. The length of the rachilla and length of its hairs are relatively constant for an agricultural variety. The color of the hulls and aleurone can be used in some cases for identification purposes.

Inheritance. The barley plant naturally self-pollinates. Even though there is some natural cross pollination, the percentage is low. There are seven linkage groups in cultivated barley corresponding to the seven haploid chromosomes. Robertson, Wiebe and Shands (12) have reviewed the barley linkage groups. Approximately 180 characters have been identified in barleys, and some have been assigned to specific linkage groups. While there are many characters whose inheritance is not understood, the genetics of barley is more completely understood than in most plants. The outstanding exception is corn.

Production

The world barley production for the ten-year period 1935–44 averaged about 2.34 billions of bushels annually. This production is somewhat greater than that of rye but is less than that of other cereal crops. On a bushelage basis rice leads all cereals in production and is followed in order by wheat, corn, oats, barley and rye. However, the total tonnages of wheat and rice are approximately equal. Likewise their tonnages are greater than that of corn, oats or barley.

The leading countries in barley production are Russia, China, United States, Canada, Germany (pre-World War II), India, Great Britain, Poland, Japan, Spain, Korea, Czechoslovakia, Denmark, France and French Morocco. Each of these countries usually produces in excess of 50 million bushels annually.

The acre yields of barley are greatest in the low countries of western Europe. Denmark, Netherlands and Belgium have yields of 50 to 55 bushels per acre annually. Ireland, United Kingdom and Switzerland frequently produce as much as 40 bushels per acre or more. Sweden, Norway, New Zealand and Egypt usually produce from 30 to 40 bushels per acre. The United States averaged about 22 bushels per acre from 1935 to 1944, but production has been almost ten percent higher in more recent years.

The leading States for barley production in the United States are in the approximate order: North Dakota, California, Minnesota, South Dakota, Nebraska, Colorado, Montana, Idaho, Wisconsin. There have been many shifts in areas of production in the United States since barley was introduced in precolonial times. In the early days of the United States, Weaver (15) points out, the two centers of barley production were largely in New York State and California. However, there was a gradual shifting westward from the New York area into other places of better adaptation until about 1900, after which time there have been significant shifts, mostly within different regions of the United States. For example, Kansas and Nebraska were relatively low barley producers in the 1930's but gained in acreage in the early 1940's and then receded. In Wisconsin the acreage reached nearly a million in 1935 but gradually dropped to less than 100,000 acres in 1945; there has been a recent increase to approximately 200,000 acres. Likewise there have been fluctuations in the barley

acreage of North Dakota, Minnesota and South Dakota. Some of the earlier shifts have been concurrent with human population changes and migration, while others have resulted from changes brought on by barley disease or insect pests.

ern hemisphere. The soil is then ready for disking in spring when the weather moderates and frost leaves the soil. This procedure tends to reduce weed populations and gives higher yields.

Spring plowing is done on a considerable portion of the fields used for barley production. However, this practice or that of only spring disking delays the seeding date somewhat and invites weed competition.

FIG. 5. Scabbed barley kernels. Top row not infected; bottom two rows show darkening from infection by *Gibberella zeae*. Hogs become sick if they eat scabbed barley.

Culture

Seedbed Preparation. Seedbed preparation is the first step in producing a profitable crop of barley. In those sections of the world where spring barleys are sown, it is considered good practice to fall plow the land. This can be done in October and November in the north-

Rotation. It is considered good practice to rotate barley fields. While barley sometimes follows barley, it is better to follow another crop, for example, corn. In some areas corn is fertilized rather

heavily and the barley receives none. Legumes are needed to improve soil structure and increase humus. Sometimes fields previously producing hay are used for barley production. This practice tends to increase soil nitrogen and lodging of the straw. In lower rainfall areas some fields are fallowed during the summer preceding a crop year

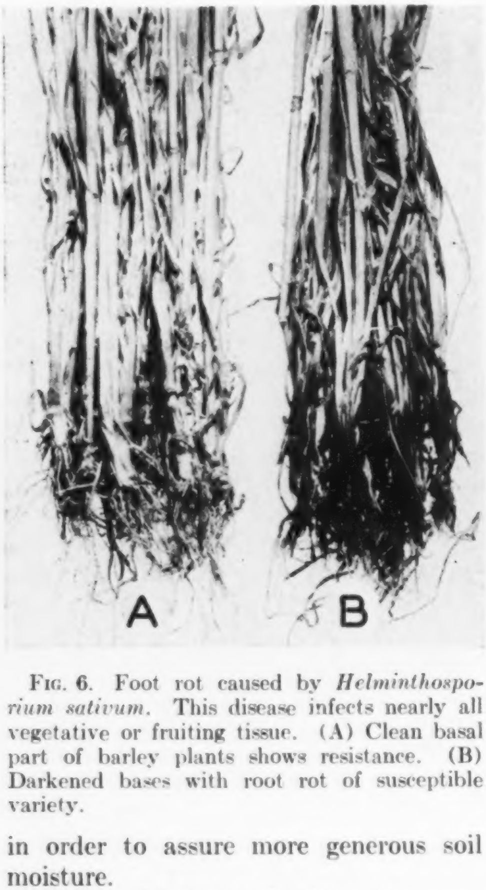


FIG. 6. Foot rot caused by *Helminthosporium sativum*. This disease infects nearly all vegetative or fruiting tissue. (A) Clean basal part of barley plants shows resistance. (B) Darkened bases with root rot of susceptible variety.

in order to assure more generous soil moisture.

Seeding Method. Drilling is recommended over other methods of seeding. Broadcast seeding usually is wasteful of seed and does not insure uniform depth, spacing or covering of kernels. Germination and stands may not be uniform or satisfactory. Where farm machinery is scarce, seed is sown by hand and covered by a drag or harrow, but this is not so efficient as drilling.

Rate of Seeding. The rate of seeding is influenced somewhat by the soil moisture, variety and time of seeding. Usually one and one-half bushels per acre provide sufficient plants to produce a good crop. Thinner seeding rates are recommended in drier areas or for soil not heavily infested with weeds or weed seeds. However, many fields sown to barley have enough weed seeds to provide early competition with the young crop. This necessitates thicker seeding rates for the barley to shade the soil before weeds become large enough to compete for soil moisture and fertility. Seeding rates for friable soils may be less than for soils that are heavy and likely to crust. Since crusting will reduce stands materially, heavier seeding rates are better. In this case rotary hoes can be used to break the crust if barley is not used as a nurse crop.

Depth of Seeding. The depth of seeding should be from one-half to one and one-half inches, great enough for the seed to come in contact with soil moisture but not enough to cause trouble for the young plant to reach the surface of the soil. Furthermore, deeper seedings not only reduce the stand but subsequently may weaken straw standing ability.

Time of Seeding. The time of seeding varies with location. Considering the world over, barley may be seeded every month of the year. In the northern hemisphere spring barley is sown from February to June, but the usual date is between April 1 and May 15. Spring varieties are sown in California from late in October to as late as mid-January. Most winter barley is sown between September 15 and October 31. Earlier seeding dates are used where fall grazing is practiced.

Nurse Crop Usage. Where grasses and legumes are seeded for hay crops, barley makes a good nurse crop. The barley is seeded with a drill at a somewhat thinner rate so as to lessen competition for the

young grass and legume seedlings about to be established. Even though barley leaves are usually broader and may be longer than other small grain crops, barley still is very satisfactory in establishing hay crops.

Fertilizers. In many areas of the world barley would benefit by proper use of fertilizers. This is especially true where soils are light and tend to leach under high rainfall conditions. Furthermore, yield is increased by top dressing with nitrogen when soils are poor. However, most barley is produced on soils that are relatively high in fertility, thereby requiring little extra fertilizer. In these areas phosphorus and potassium are the principal elements added to the soil. It is becoming profitable, however, to add small amounts of nitrogen to the fertilizer mixture. The added fertilizer elements may be of benefit to succeeding crops.

Lodging. Lodging is one of the main problems in barley production. It may be caused by any one of several factors, such as poor root system, poor culm structure, improper fertilization, heavy disease infections and storm damage. Lodging can be reduced to some extent by proper cultural practices, for instance, balancing the fertility, seeding spring barley at early dates and planting adapted varieties that are resistant to root rots and leaf spots.

FIG. 7. Field of shocked barley in Wisconsin.

Disease and Insect Pests

Barley has about as many disease and insect pests as any other small grain, and there are some workers who believe barley is beset with more troubles than other cereal crops. There are times when almost any disease may be of major importance in reducing the yield. One of the surest ways to prevent major losses from disease or insects is to use adapted varieties that have been grown successfully for a long time in a given locality. These adapted varieties may not be completely disease resistant, yet they have enough resistance or tolerance to the diseases that frequently occur in the area; otherwise the varieties would not have persisted. Breeding varieties that will resist pests is complicated by the fact that pathogenes and insects shift in populations. Little known races of pathogenic organisms may rise to preva-

lence and attack varieties that previously were resistant to the older races. To some extent cultural practices, such as seed treatment, early seeding dates and proper seeding methods, may be used to reduce disease losses. Dickson (7) and Shands and Shands (13) have described several of the important barley diseases.

Smuts. Loose smut induced by *Ustilago nuda* (Jens.) K. and S. causes the head of barley to be replaced by a brown spore mass that blows away, leaving the bare rachis. The smutted heads make their appearance about the same time that healthy heads emerge from the boot. The smut spores from the diseased head may be blown by the wind or carried by a spattering rain to young flowers of healthy heads where the spores germinate and are likely to grow into the developing young seed. The kernel thus infected shows no visible signs of disease, but the following year it will produce smutted heads. This is one of the most difficult of all barley diseases to control. Mercury dusts or formaldehyde do not control it. Since most of the agricultural varieties are susceptible, the only effective control is by the hot water treatment of seed.

The second or intermediate loose smut is caused by a closely related fungus. The diseased heads may be seen in the field a little later than those of the first loose smut. This smut is similar in appearance to the former, and therefore the two can easily be confused. Sometimes the head is not completely replaced by the smut spores; instead some of the awns remain and even part of the hulls may be left intact. The spores may be distributed as late as threshing time; they are carried on the seed, and infection occurs at the time of seed germination in the field. This loose smut can be controlled by treating the seed with one of the proper mercurial compounds. A few varieties resist the intermediate loose smut.

Covered smut disease is caused by *Ustilago hordei* (Pers.) K. and S. Diseased heads infected with it have symptoms distinctly different from heads of the two loose smut diseases. A thin membrane encloses the smut mass, and the awns have a decided tendency to remain on the head. The heads are more rigid and do not shed the spores as readily as the loose smuts. Smutted heads are crushed during threshing, and spores are distributed to the surface of the kernels. At the time of seed germination in the field, the spores become active and infect the young seedlings. Covered smut also can be controlled by proper mercurial seed treatments. Some varieties resist this disease.

Stripe Disease. Stripe disease of barley is caused by *Helminthosporium gramineum* Rabh. Pale stripes appear on the leaves as early as late May in spring barley areas. Later the stripes become brown and even black, at which time leaves are shredded. The striped plants are generally smaller and have less root and top growth than neighboring healthy plants. Frequently the head does not emerge from the boot. The diseased leaves produce abundant spores which are carried by various means to the healthy flowers. Spores lodged on healthy flowers may infect immediately or may remain dormant until seed germination in the field. The disease can be controlled by proper organic mercury treatment of the seed or by resistant varieties.

Spot Blotch. Spot blotch disease is caused by the fungus *Helminthosporium sativum* P. K. and B. and is associated with warm wet weather conditions. This fungus lives on seed, straw and stubble in contact with the soil. It is safer not to grow barley on the same land in successive years. The disease causes head blight, flower sterility, spotted leaves, rotted nodes and foot rot. Heads may not emerge completely. Seed treatment with organic mercury kills the organism on the seed but does not control the dis-

ease on leaves, stems and heads. Most commercial varieties are moderately resistant to this disease.

Net Blotch. Net blotch is caused by the fungus *Helminthosporium teres* Sacc. The disease causes head blight and brown netted streaks on leaves, and sometimes kills leaves under wet cool conditions. Diseased leaves may become useless in plant food manufacture, resulting in thin kernels and reduced yields. Some of the Manchurian and Coast types are moderately resistant to this disease. Clean cultivation, crop rotation and seed treatment are advisable.

Scab and Blight. Head blight of barley is caused by the fungi *Gibberella zeae* (Schw.) Petch. and *Helminthosporium sativum* P. K. and B. It is of major importance in grading, marketing, feeding and industrial utilization of barley. Blighted kernels are darker than clean kernels, and they vary in appearance, depending on the degree of infection. Severely blighted kernels are lighter in weight than either healthy or less severely infected kernels. Gibberella blighted barley is called "scabbed barley" and is undesirable for malting; it should not be used for feeding hogs or horses, but can be fed in moderation to poultry, sheep and cattle. Often the vomiting of hogs after eating blighted barley is the first indication that barley is scabbed. Scab damage occurs more frequently during warm and humid conditions in the corn belt area of the United States.

FIG. 8. Threshing barley with a common threshing machine.

Head blight infection usually takes place between flowering and ripening of the kernels. The infecting fungi live over winter on crop refuse, especially cornstalks and stubble, and under humid conditions in the late spring produce

ascospores or conidia that infect the barley head after flowering. Rainy humid weather and lodging at the heading period or later are especially favorable for head blight diseases.

Control of the head blights lies mainly in clean cultivation and crop sanitation. Seed treatment results in earlier emergence, better stands and stronger plants where blight damaged barley is used for seed. Nearly all commercial varieties are susceptible to Gibberella head blight.

Stem Rust. Barley stem rust is caused mostly by the same organism that attacks wheat. In 1937 this disease reduced the barley yield by one-third in Wisconsin, but since 1937 it has been of minor importance in the U.S.A. and may remain so because of greater usage of resistant varieties.

Powdery Mildew. Powdery mildew, caused by *Erysiphe graminis* D. C., occurs in humid and semi-humid areas of the world on both winter and spring barleys. Some commercial varieties resist some races of the fungus. Severe infection cut yields as much as 30 percent in susceptible selections in the Madison, Wisconsin, nursery in 1942. This disease may be very important on winter barleys.

Septoria. *Septoria passerini* Sacc. is often observed on leaf sheaths where dark pycnidia (fruiting bodies) are found. The leaf spot and stem rot phases may be more damaging than realized, even though the disease is thought to be of minor importance. Clean cultivation and seed treatment may reduce damage from this disease.

Minor Diseases. There are several other diseases of barley which may cause losses when conditions are especially favorable for their development. Ergot is occasionally severe in barley where this crop is grown on poorly plowed pasture land or when quack grass is a common weed in the field. Even a relatively small number of ergot bodies in the grain will result in discounts on the market. Leaf rust is usually important in some of the winter barley areas. Several other diseases—bacterial blights, scald, anthracnose, root rots, viruses, stripe rust—may cause damage under conditions favorable for development of the causal agents in relation to the barley plant.

Insects. Insects damage barley production to about the same extent as other small grains, and production areas are sometimes restricted by their prevalence. Some of the important field insects are grasshoppers (*Melanoplus* spp.), green bugs (*Toxoptera graminum* Rond), chinch bug (*Blissus leucopteros* Say) and Hessian fly (*Phytophaga destructor* Say). Any of these insects can limit production when conditions are favorable. The green bug is known to be particularly damaging in fall-sown barleys in some areas of the world. Chinch bug has limited production in some of the north central States. Billbugs (*Calendra* spp.) have been found in the basal part of barley stems, and some infestations suggest that these insects can inflict heavy damage. Other insects also may attack barley.

Harvesting

Time. Harvesting should be done only when the grain is fully ripe. This affords greater yields per acre and also improves the quality for industrial processing. The barley is ripe when the moisture content is 14 percent or less. This is a relatively safe moisture percentage for storage purposes, but most farmers do not have access to moisture-testing machines. In this case the grain should feel dry to the hand and should snap when a kernel is bitten between the teeth. There is a general tendency for farmers to cut the grain while the straw is immature. This sometimes produces a brighter colored grain but usually reduces yields and quality when compared to the grain left standing for an additional time.

Method. In some areas of world production, barley is harvested and threshed in a rather primitive manner, using human and livestock effort. In other locations where machines are more widely used, the combine is the principal harvesting machine. Combining is the cheapest method of harvesting barley in the United States and Canada because it requires less manual labor. The combine is used to harvest either the standing grain or the windrowed grain which was cut a day or two previously. In drier climates the standing grain is more easily combined. However, where humidity is greater, windrowing is frequently used. This affords drying of the more immature heads as well as weeds that usually occur in barley fields. Combining should be done when the moisture content is 14 percent or less.

A windrow machine cuts the grain and lays it in rows on the stubble. A binder without the knotter performs similarly. After the grain is properly dried, the pick-up attachment elevates the grain to the combine for separation. Windrowing introduces hazards of unfavorable weather, and this may result in deterioration of the crop, an effect which is offset by quality improvement if no rain falls while the grain is drying in the windrow.

When grain is cut with a binder, later to be threshed with a threshing machine, it is desirable to shock the barley immediately and to cap the shocks with bundles. This affords protection against weathering, rains and sprouting in the shock, and tends to produce a brighter colored grain. In a few cases barley is stored in a barn or stacked in the field before threshing. This method gives the best protection against weather damage, but requires a great deal of labor.

The greatest part of the barley crop in

FIG. 9. Harvesting barley with self-propelled combine.

the United States is harvested with the combine, yet a considerable portion is cut with a binder and threshed by an ordinary thresher. With both methods barley kernels need to be threshed so as to eliminate skinning and breaking. Since moisture content of the grain changes from early morning to late in the day, adjustments should be made in the manner of handling the machines. Skinning and kernel cracking may be reduced or eliminated by properly adjusting the cylinder speed during the day. The thresher also may need levelling. Furthermore, uniform bundle feeding is desirable. Adjusting the chaffer and sieves will frequently improve the threshed grain appearance.

Storage. Most of the grain is stored in wood, concrete or steel bins. Sometimes the grain is shovelled into these containers and at other times it is elevated into the bins by buckets on an endless chain, or a blower. If the blower is improperly set, skinning and breaking of grain may result, lowering the commercial grade. A small amount of the crop is used for seed, and part of this is stored in bags. Grain stored in bags tolerates higher moisture without spoiling than bulked grain in the bins.

When the moisture of bulk grain is in excess of 14 percent, it may heat and go out of condition. In the bin a post-ripening process takes place which has a tendency to increase grain temperature and moisture. If there is free moisture, molds start growth and increase the temperature. Heat damage may be reduced or prevented by maintaining low temperatures during storage. By taking the grain temperature at daily intervals for a few weeks it is possible to learn the storage condition accurately. If there is a significant rise in temperature, the grain should be aerated by one method or another. Some farmers have found it very satisfactory to shovel the grain from one storage location to another. Others have found it satisfactory to aerate the grain by running it through a fanning mill. Elevator operators some times transfer the grain from one compartment to another, aerating and cooling the grain during the process, or they may artificially dry the grain.

Insects sometimes create storage problems in different parts of the United States. Ordinary grain weevils destroy large amounts of barley. There are also areas where the grain beetles are destructive. Two grain beetles known to be destructive are the foreign grain beetle (*Ahasversus advena* Waltl.) and hairy fungus beetle (*Typhaea stercorea* L.). Fumigation with a mixture of about three-fourths ethylene dichloride and one-fourth carbon tetrachloride will eliminate most storage insects. As little as two quarts will be sufficient to treat 100 bushels of grain.

Processing of Grain

The following discussion on the processing of barley will be limited primarily to the procedures used in the United States, although certain differences in other countries will be pointed out.

Feed. The largest percentage of barley is used for animal feed. This use involves simply grinding the grain to be fed to most types of livestock. It is done commercially in the preparation of mixed feeds, although large quantities are also ground in small batches on farms. In some parts of the United States, particularly the more western areas, barley is rolled for feeding. The grain is steamed or tempered to a limited degree and put through corrugated rollers, aspirated and then bagged.

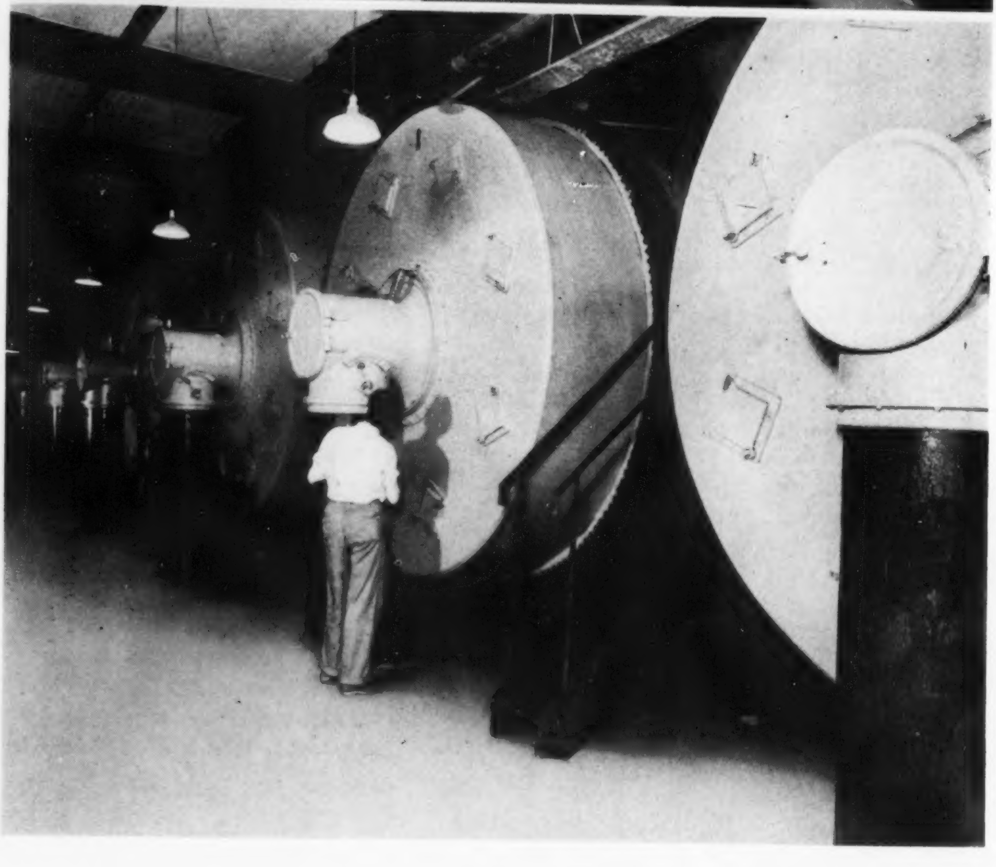
Malting. The second largest quantity of barley is used for malting. This is a controlled germination process of relatively short duration at cool temperatures. The malting process, recently described in detail by Dickson and Kneen (8), involves three steps—steep-

ing, germinating and kilning. Before malting, barley is steeped to approximately 45 percent moisture in cold water in large cylindrical tanks. The tanks are equipped for aeration and water overflow to clean the barley and supply fresh air and water for steeping. After approximately two days of steeping, the barley is conveyed to germination equipment consisting of drums or compartments, the two types used in the United States. In both cases humidified and temperature-controlled air is drawn through the germinating grain. Mechanical devices turn the barley to prevent matting of rootlets and also to assist in controlling temperature. In floor malting, which is still used in European countries, the grain is spread on floors of cool ventilated rooms. Hand turning with forks cools the germinating grain and controls rootlet growth. The length of germination time is usually from five to seven days at temperatures from 60° to 70° F. During this period rootlets develop, and the plumule or acrospire grows under the hull of the barley. The ideal end point of growth is to have nearly 100 percent of the kernels with the acrospire just the length of the kernel.

At the end of the germination period the "green" malt is conveyed to large kilns and spread in layers from two to three feet deep. These kilns consist usually of two or three floors, and the heat, supplied by coal, oil or gas furnaces, is drawn up through the grain. Drying is started on the top floor at a relatively low temperature. After approximately 24 hours the malt is dropped to the lower floor where the final drying takes place. The malt is then dumped into hoppers below the kiln, cleaned to remove rootlets, and conveyed to storage.

FIG. 10. Skinned and broken barley kernels damaged by improper threshing. Market quality is reduced by careless threshing or combining.

In the United States two general types of malt are produced, brewers' and distillers'. The former is germinated at a medium moisture content and is kilned at high temperatures to a final moisture



of about four percent. This results in malts high in flavor and aroma. Distillers' malts are germinated at relatively high moisture levels and dried under milder conditions to approximately six percent moisture. These conditions favor the production and conservation of high enzymatic activities.

Specific varieties of barley and barley from specific areas of production are preferred for malting. The largest percentage of malt is made from six-rowed spring barleys grown in the northcentral part of the United States. Smaller quantities are made from two-rowed barley from the Northwest and intermountain areas, and six-rowed coast types from California.

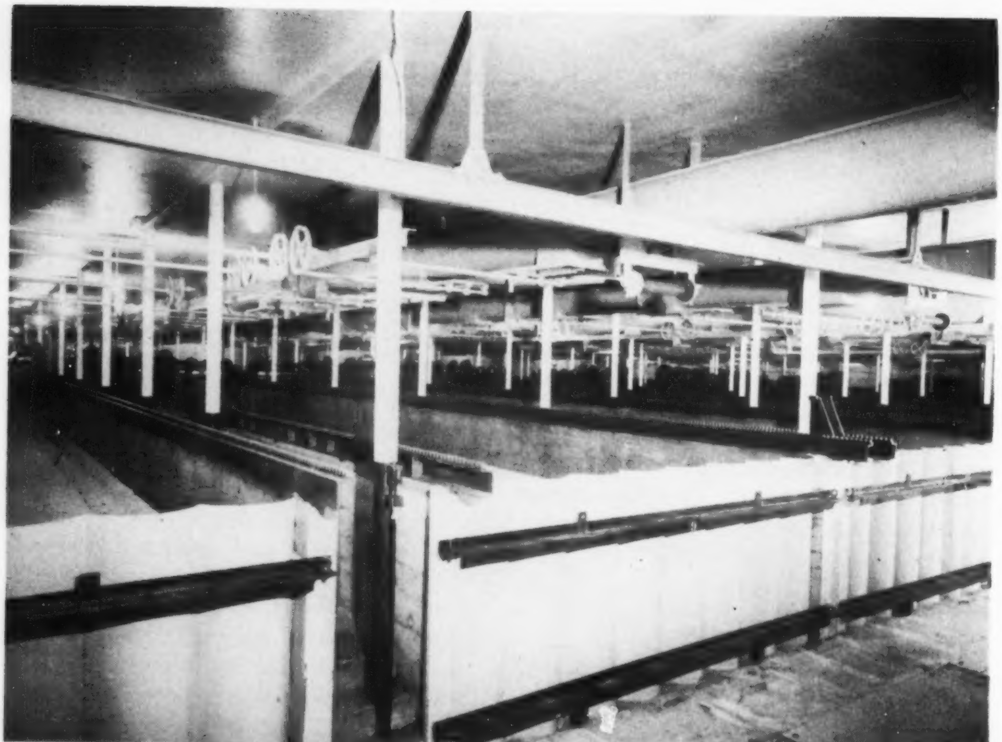
During the germination phase of malting, enzymes are produced or liberated in an active state primarily in the epithelial layer of the scutellum. This structure is located between the germ and endosperm of the kernel. The cytases diffuse through the endosperm of the kernel and change the cell wall material. This results in a mellow friable malt in contrast to the hard barley. Other enzyme systems, capable of hydrolyzing the proteins and starch, are produced and form sugars and amino acids which serve as nutrients for the growing seedlings. At cool temperatures it is possible to obtain rather extensive activation of the several enzymes but limit the hydrolysis and depletion of the endosperm reserves. However, respiration and germination processes result in a loss of material. Also the rootlets are removed from the dried malt and constitute a second loss. They are sold primarily for feed. These combined losses approximate nine percent by weight of the original barley under optimum conditions. Considering the differences in moisture of barley and malt, and the bushel weights, 48 pounds for barley and 34 pounds for malt, one bushel of cleaned barley will yield approximately 1.15 bushels of malt.

Enzymatic activity of malt largely determines its use. Of the enzymes concerned, probably the amylases or starch-splitting enzymes are of most importance. Barley contains bound beta-amylase which is liberated and activated in the malting process. Alpha-amylase is produced during germination, probably by synthesis. Several other enzyme systems are also either produced or activated. During kilning of brewers malts desirable flavor and aroma are developed. However, there is moderate destruction of enzymes except for alpha-amylase which persists under average drying conditions. As indicated in the discussion of the two types of malt, the characteristics of the finished product can be controlled within limits by the processing conditions. Also, different types of barley and different varieties within a type produce malts which differ in characteristics. Those barleys which produce a desirable combination of enzymatic activity and chemical composition upon malting are classed as malting varieties and bring a substantial premium over feed barleys.

Pearling. Most of the barley which is used for human food in the United States is pearled. In this process, described by Geddes (9), abrasive disks revolving within a perforated cylinder grind off the hulls and the outer layer of the kernel. The disks are usually coated with carborundum or emery and revolve at about 450 r.p.m. The cylinder is designed to keep the barley turning and give uniform removal of material. This is usually a batch process,

FIG. 11 (*Upper*). Steeping barley in a commercial malt house. After cleaning and sizing, the barleys are steeped in cold water in large tanks.

FIG. 12 (*Lower*). Malting drums in a commercial plant where the steeped barley is germinated. Cool humidified air is drawn through the grain. The drums revolve very slowly to stir the malt.



often controlled automatically. The grain is pearled for a few minutes, then transferred to a screen for sifting out the hulls and other material, aspirated to remove fine particles, and finally cooled. The cooled grain is submitted to a repetition of the same steps.

After three pearlings all of the hull and most of the kernel coating have been removed, and the dehulled grain may then be graded as to size and sold as pot barley. After five or six pearlings all of the kernel coating and practically all of the embryo are removed, and the remaining product is marketed as pearled barley. One hundred pounds of barley will yield approximately 65 pounds of pot barley or 35 pounds of pearled barley. The ground material from the process may be separated into barley flour and other parts of the kernel which are used for animal feeds. Barleys with large uniform-sized kernels are preferred for pearling. White two-rowed varieties are most commonly used.

Milling. Only relatively small quantities of barley are used as flour in the United States. In Asiatic countries, where much larger percentages of the total barley production are used for human food, much of it is utilized as barley flour or grits. In these countries hull-less or naked barleys are often employed, since they yield a higher percentage of flour. In Japan, for instance, naked barley may yield up to 88 percent of a rather crude flour, while hulled varieties would yield only 70 to 75 percent. As indicated above, barley flour is an important by-product of the pearling process. This is particularly true of the later pearlings, that is, fourth, fifth and sixth, since in this case the starchy endosperm primarily is being removed. This material may be further milled or merely bolted and aspirated for production of flour. Pearled barley is milled further into a high grade patent flour. Barley flour may be produced also by roller milling, bolting and purification similar to the process used for wheat. In this case hulls of the grain are often removed before milling.

Utilization and Economics

Hay, Grazing, Cover Crop. Barley is cut for hay in rather limited areas, especially the western part of the United States, where other hay crops are difficult to grow. For this purpose it is cut while still green but after the heads are well formed. The partially matured grain adds materially to the feed value of the hay, since protein is high in early stages of grain filling.

In winter barley areas the crop is pastured in the fall after it is well established and several inches tall. In the spring it is again pastured for a time and then allowed to grow and produce a crop of grain. For prevention of soil erosion, barley is important also in these areas as a winter cover crop. In these rather extensive regions this versatile crop supplies pasture in two seasons, protects the soil from washing and yields a crop of grain. It is also used as a winter cover crop and as a green manure crop in the spring.

Straw. Barley straw is not utilized to any extent in industry, but large quantities serve as bedding or roughage in livestock-producing areas. When not needed for these purposes, it is returned to the land and plowed under or incorporated into the surface of the soil to prevent soil washing or blowing.

Marketing and Grading. Like other

FIG. 13 (*Upper*). Commercial malting compartments are large concrete bins with perforated metal bottoms. Conditioned air is drawn up through the malt to maintain temperature and humidity. Mechanical turning devices prevent the matting of grain during germination.

FIG. 14 (*Lower*). One floor of a commercial kiln for malt drying. The turning machine in the left background levels out the malt and facilitates uniform drying. Heated dry air is drawn up through the grain by large fans above the kiln.

grains, barley is sold largely by grade in the western world. Barley grading in the United States was uniformly established by the Grains Standardization Act of 1916. Grading of barley is an attempt to evaluate quality on the basis of standard determinations made at the marketing centers. When properly administered, this results in barley of good quality selling at higher prices than poor barley from the same community.

For grading purposes in the United States barley is divided into four classes: Class I, Barley, white-glumed barley grown east of the Rocky Mountains; Class II, Black Barley; Class III, Western Barley; and Class IV, Mixed Barley. Some of the factors used in establishing grade are admixture with other classes of barley, test weight per bushel, percentage of sound barley, percentages of heat damaged kernels, foreign material and broken kernels, moisture content, and percentages of diseased kernels. Special grades for malting barley have been established for Class I, Barley, and Class III, Western Barley. These grades apply additional restrictions on admixtures of non-malting types or varieties, percentage of small kernels, skinned and broken kernels and on steeliness of the kernel. When barley meets malting grades it usually brings a substantial premium in price over feed barley. Therefore, the grower profits by using preferred varieties and by harvesting, threshing and storing his grain properly in order to qualify for the higher price.

Feed. Barley is an excellent feed grain with a feeding value about 95 percent that of corn. It is highly prized as a feed for bacon hogs. Desirable proportions of firm white fat and lean meat are produced when barley is the principal feed grain. In North America the major use of the crop is for animal feed, and relatively small amounts go into human food. In other parts of the world, especially the Asiatic countries, the quantities consumed by human beings assume major proportions. Approximately 40 percent of the 1948 and 1949 United States barley production was used on the farm for feed and 60 percent sold as a cash crop for other purposes. During the ten-year period from 1940 to 1949 an average of 200 million bushels per year was used for feed, which represents about 65 percent of the average total production for the period.

The yearly total production from 1940 to 1949 varied from 238 million to 430 million bushels. The average price per bushel received by farmers ranged from a low of 40 cents to a high of $1.70. During this ten-year period the market value of the entire barley crop was estimated at three billion dollars to the producers or an average yearly value of 300 million dollars. The period selected was about average in production, but the average price per bushel was much higher than in earlier years. It is difficult to estimate the value of barley fed on the farm and marketed in the form of livestock or its products, but its value should have exceeded the average price per bushel considered above and therefore have increased the yearly value.

Industrial and Food Products. The major industrial use of barley is for malting. Although several cereal grains are malted throughout the world, barley is the principal malting grain in the United States. Since barley was probably the first cereal grain grown and was used by the ancients for fermented beverages, its use for malting and beer production is based on tradition. Also, the hull on the barley, the physical texture of the kernel, and the enzymes produced by malting adapt it to this industrial use. Considering the same ten-year period discussed above, an average of 30 percent of the total barley production was used for malting. During the last six years of this period (1944–1949) barley production decreased while the production of malt gradually increased and

the percentage used for malting rose to 37 percent. Over this same period approximately 100 million bushels of barley went for malting annually. Malt is not used as such but requires further processing for products of industry. The great diversity of uses is indicated in Table I (11).

In recent years about 80 percent of the malt production has been used for manufacturing beer. Malt makes up from 50 to 70 percent of the dry mate-

TABLE I

USES OF BARLEY AND BARLEY PRODUCTS

- Feed
  - livestock
  - poultry
- Export
  - feed
  - malting
- Pearling
  - pot barley, pearled barley
    - soups
    - dressings
  - flour
  - feed
- Milling
  - flour
    - baby foods
    - food specialities
  - grits
  - feed
- Malting
  - brewers'
    - beverages
    - brewers' grains—dairy feeds
    - brewers' yeast
      - human and animal feed
      - fine chemicals
  - distillers'
    - alcohol
    - distilled spirits
    - distillers' grains, distillers' solubles
      - livestock and poultry feeds
  - speciality malts
    - high dried, dextrin, caramel, black
      - breakfast cereals
      - sugar colorings
      - dark beers
      - coffee substitutes
  - export
  - malt flour
    - wheat flour supplements
    - human and animal food products
  - malted milk concentrates
    - malted milk
    - malted milk beverages
    - infant foods
  - malt syrups
    - medicinal
    - textile
    - baking
    - breakfast cereals
    - candies
  - malt sprouts
    - dairy feeds
    - vinegar
    - industrial fermentations

rials going into beer in the United States. Rice or corn products, which are high in starch, are used as adjuncts in beer production. The brewing process involves grinding the malt, mashing with water, gelatinizing the starch of the adjunct, and converting all of the starch to fermentable sugars and dextrins. Proteins and other constituents of the malt are also changed during the mashing and conversion. The filtered extract of malt and adjuncts, known as wort, is boiled with hops, filtered, cooled and fermented with brewers' yeast. The fermented beer is aged, chill-proofed, filtered, bottled and pasteurized in the production of bottled beer. Draft or keg beer is handled in a similar fashion except that it is not pasteurized. A few of the larger breweries produce enough malt to satisfy all or a portion of their needs, but most of the malt is produced by commercial maltsters and sold to the brewers.

From ten to 15 percent of the malt production is distillers' malt, and this is used primarily for the production of industrial alcohol, distilled spirits and whiskey. In this process, from ten to 15 percent of malt is used to convert 85 to 90 percent of corn or other starchy grain to fermentable sugars which in turn are fermented into alcohol. The distillery mash is fermented without filtration or boiling, and the alcohol is removed by distillation.

The remaining uses of malt indicated in Table I require only five to ten percent of the total production. Examples of these are numerous types of malt syrups for specific uses, malted milk concentrates, amylase supplementation of wheat flour and breakfast foods.

Food uses of unmalted barley probably require less than ten million bushels annually. Pot and pearl barley production is the most important use, requiring an estimated three million bushels per year. In the United States small quantities of barley flour are used in infant foods and other food specialties, but practically none in bread. In other countries, especially Asia, large quantities of the grain serve this purpose.

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Acknowledgments

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The Role of Fungi in Cheese Ripening[1]

Fungi are important in the manufacture of two types of cheese—blue-veined cheeses, and Camembert and Brie. Among the former are Roquefort, Gorgonzola and Stilton, dependent on the mold Penicillium roqueforti and the bacterium Streptococcus lactis. Camembert and Brie require Penicillium camemberti and lactic acid-producing streptococci; the mold Oospora lactis and the organism Bacterium linens may also play roles in their manufacture.

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Introduction

Mold-ripened cheeses were manufactured and consumed in large quantities long before dairy microbiology acquired any importance. For many years the role of fungi in cheese-ripening was not clearly understood, and yet during this time cheeses of excellent quality were manufactured. Recent studies on the growth and chemical activities of fungi in cheese-ripening have resulted in the adoption of scientific procedures for cheese manufacture which permit a large proportion of the products to be uniform in flavor.

[1] Published with the approval of the Director of the Purdue Agricultural Experiment Station as Journal Series Paper No. 599.

Fungi are important in the manufacture and ripening of two types of cheese, namely, the blue-veined cheeses and Camembert cheese. Both types had their origin in France. The blue-veined cheeses, as their name implies, are those in which blue-green mold can be seen growing throughout their interior. Common among the blue-veined varieties are Roquefort cheese manufactured from sheep's milk and originating in France, Gorgonzola made from cow's milk and originating in Italy, Stilton cheese manufactured from cow's milk and originating in England, and various types of Blue cheese or Roquefort-type cheese manufactured from cow's milk in the United States and many other countries. Camembert is characterized by a white mold growth on the surface and a soft texture when properly aged; it is about one inch thick and four inches in diameter. Cheese manufactured by the Camembert procedure and identical to Camembert except for their larger diameter are Brie cheese. Both Camembert and Brie are made from cow's milk.

Blue Cheeses

Early History in the United States. Prior to 1900 various individuals and cheese companies attempted to manufacture blue-veined cheese from cow's milk in the United States with the idea

of duplicating the Roquefort cheese imported from France. None of the attempts was successful. In 1903, Professor H. W. Conn of the Storrs Agricultural Experiment Station, Storrs, Conn., began a systematic microbiological study of blue-veined and Camembert cheese (3). Molds were isolated from many imported cheeses and their physiology studied. Later, investigations were conducted jointly by the Storrs Experiment Station and the United States Department of Agriculture. Some success in the manufacture of a Roquefort-type cheese was attained and methods for manufacture were published (19). However, large-scale commercial production did not result. Renewed interest in blue-veined cheese was evident after World War I, and in 1921 a bulletin on the manufacture of cow's milk Roquefort was published by Matheson of the United States Department of Agriculture (14). One of the criticisms of the domestic cheese concerned its yellow color, especially when milk was obtained from cows on pasture.

In the early 1920's an appreciable amount of goat milk was available in California, and this milk appeared suitable for blue-veined cheese. Cooperation between the United States Department of Agriculture and the California Agricultural Experiment Station resulted in a series of investigations and the publication of a method for the manufacture of Roquefort-type cheese from goat's milk (8). The cheese thus manufactured was whiter than cow's milk cheese and more similar to Roquefort. Later, Goss et al. (7) of the Iowa Agricultural Experiment Station published a procedure for the manufacture of Iowa Blue cheese.

Several commercial organizations attempted to manufacture blue-veined cheese of the Roquefort type by the various methods that were published, but, because of several difficulties, no large industry resulted. The difficulties encountered included failure of the mold to develop properly, yellow-colored cheese, no development of the characteristic flavor in a reasonable length of time and lack of uniformity among lots. Also, the cost of manufacture of the domestic product was greater than that of the imported.

Some of the early experimental work on the flavor of Roquefort was conducted by Currie (4) who pointed out that the flavor is partly due to the accumulation of caproic, caprylic and capric acids during ripening.

Lane and Hammer (12) of the Iowa Agricultural Experiment Station concluded that if fatty acids were responsible for the flavor of Blue cheese, perhaps the flavor could be produced more quickly if the milk were homogenized before being made into cheese. The homogenization process greatly decreases the size of fat globules in milk and therefore increases the fat surface. Raw milk develops a rancid flavor characterized by free fatty acids very quickly after homogenization due to the presence of milk lipase and the increased fat surface.

A preliminary report on the manufacture of Blue cheese from homogenized cow's milk was published in 1936 (12). These experiments indicated that the curd obtained from homogenized milk was more flaky and had less yellow color than cheese prepared from nonhomogenized milk. Another important characteristic of the homogenized milk cheese was that mold growth was more luxuriant. The cheese manufactured from homogenized milk developed a definite rancid flavor early in the ripening period, and there was evidence of free butyric acid. Later in the ripening period, the cheese made from homogenized milk were no longer rancid, nor was there evidence of butyric acid. The disappearance of rancidity and butyric acid was accompanied by the development of a

sharp peppery flavor characteristic of Roquefort cheese.

The method of manufacturing Blue cheese by use of homogenized milk (13) was quickly accepted by the cheese industry. Individuals and cheese plant operators began a search for suitable locations for factories which had natural ripening facilities. An abandoned brewery along a river at Faribault, Minn., was chosen as the site for one cheese factory because a cave in the bank at the side of the plant appeared to have ideal temperature and humidity conditions for blue-veined cheese. The French people who settled at Nauvoo, Illinois, many years ago used caves to age wine, and these caves provided a site for another Blue cheese factory. Another series of caves were located near the Mississippi River at St. Paul, Minn., and cheese was transported to those caves for curing. Abandoned coal mines and mushroom cellars were converted to ripening rooms. Besides these natural ripening facilities, many curing rooms were constructed and fitted with temperature and humidity controls. An extensive Blue cheese industry was operating in the United States prior to 1939 or within three years after the homogenization process was developed.

Present Manufacturing Procedure. The manufacturing procedure used by a large number of Blue cheese manufacturers in the United States today is as follows:

Whole milk containing approximately 3.5 percent butterfat is warmed to 85° F and separated. The skimmilk is directed into the cheese vat, and the cream is run through a homogenizer operating at 2500 pounds pressure per square inch. The cream from the homogenizer is directed to the cheese vat and mixed with the skimmilk. During the season when cows are on pasture, it is common practice to bleach the fat of milk with benzoyl peroxide so that cheese having a uniform color throughout the year can be manufactured. One percent of an active culture of lactic acid-producing streptococci is added to the milk in the cheese vat. The milk in the vat is adjusted to 90° F and allowed to stand for about one hour in order to develop a small amount of lactic acid. The period allowed for growth and acid production is known in the cheese industry as the ripening period. After the ripening period, a solution of rennet is added to the milk at the rate of three or three and one-half ounces per 1000 pounds of milk. Rennet is an extract prepared from calves' stomachs which contains a definite quantity of the enzyme rennin. In the manufacture of Blue cheese, the milk shows signs of coagulation 12 or 15 minutes after the addition of rennet. However, the rennet is allowed to act on the cheese milk for one hour so as to form a firm coagulum and to permit more acid production by the lactic culture. The time during which the rennet is permitted to act is known as the setting period. After the setting period, the vat contents appears as a firm smooth coagulum. The coagulum is then cut with curd knives into cubes about one-half inch square. After cutting, the curd particles are not disturbed for about 15 minutes to permit them to firm slightly and to allow whey to be expelled from the particles. Throughout the entire manufacturing procedure the vat contents are maintained at 90° F. About 15 minutes after cutting, the contents of the cheese vat are stirred slowly. Stirring assists in the removal of whey from the curd particles and aids in firming the curd. The stirring is intermittent and generally carried out for one to one and one-half hours. The time of stirring is dependent upon the rate of acid formation and the rate of firming of the curd. It is desirable to produce a firm curd with as low acid production as possible. When the curd particles seem firm, all

or a portion of the whey is drained from the vat. Some manufacturers prefer to dip the curd out of the whey onto a draining rack in order to prevent the curd particles from matting, while others prefer to drain all of the whey from the vat. The latter method is more time-saving but may result in considerable matting if not carried out rapidly. Excessive matting is undesirable because mold powder cannot be mixed evenly with the curd, excessive fat loss may take place if the matted curd is broken, and the curd may have too close a texture (curd particles too closely knitted together). After the curd is drained free of whey it is mixed with one percent salt and approximately 0.01 percent of mold powder (*Penicillium roqueforti*). The curd is placed in perforated forms about seven inches in diameter and eight inches high with open ends. The forms or curd hoops are placed on a table covered with open-textured cloth, wire mats or perforated metal sheets. The curd quickly mats and assumes the shape of the hoop. The cheese are turned in the hoops each half hour for two hours, each hour for the next six hours, and once every two hours for the next eight hours. By this time the cheese are firm and can be removed from the hoops to the salting room. The salting room is maintained at 50° to 55° F and 95 percent relative humidity. The cheese are salted by applying dry salt to the surface each 24-hour period until the cheese contain about four percent salt.

After the cheese are salted, they are pierced (skewered) on the flat surface with wire needles so that a punch hole occurs in each three-quarter square inch area. When punched, the cheese are ready for the curing room. Curing or ripening is accomplished by holding the cheese at a temperature of 50° to 55° F and 95 percent relative humidity for about three months. Before the cheese are marketed, they are washed and wrapped in tin foil.

Preparation of Mold Powder. During the early period of Blue cheese manufacture, mold powder was prepared by growing a strain of mold in the interior of a loaf of bread. Fresh bread or older bread was sterilized with dry heat (170° C for two hours) and then permitted to cool to room temperature. Mold spores obtained from an agar slant were suspended in sterile water and added to the bread by piercing the surface with a pointed pipette and allowing the spores to flow into the loaf. The inoculated bread was held in a moist cool place for two or three weeks to permit the mold to develop, and then removed to a dry room. When the bread was thoroughly dry, it was sliced and ground to a fine powder with mortar and pestle or by use of a mechanical grinder.

It was noted (11) that culturing mold in the above manner frequently resulted in the development of foreign molds. Also, powder with a low spore count often was obtained because of failure of mold to grow in portions of the loaf. The long time required for the mold to develop was objectionable also. The investigators compared several procedures for preparing mold powder and developed the method which is in general use at the present time. This method consists of cutting whole wheat bread into half-inch cubes. The bread is placed in Fernbach flasks, filling them about one-third full. After stoppering the flasks with gauze-covered cotton, they are sterilized by autoclaving at 15 pounds pressure for one hour. Following the heating, the flasks are shaken repeatedly during cooling to keep the bread cubes

FIG. 1 (*Upper*). Cutting curd in the manufacture of blue cheese.

FIG. 2 (*Lower*). Blue cheese being turned to facilitate whey drainage and to form the cheese. (*Photos by courtesy of Maytag Farms, Inc., Newton, Iowa.*)

from sticking together. When cool, the flasks are inoculated with a suspension of mold spores. At this time a small quantity of sterile water may be added to provide sufficient moisture for rapid mold growth. The flasks containing bread are incubated at 70° F for eight to 12 days and shaken daily during the incubation period. Appearance of mold growth within the flasks determines the incubation period. When the bread cubes attain a blue-green color the flasks are emptied onto drying trays which are placed in an oven maintained at 110–120° F. After drying, the moldy bread cubes are ground to such fineness that the powder will pass through a 40-mesh screen. The ground mold powder is placed in tin cans, sealed and held in a cool place. Mold powder prepared in this manner will have a spore count of 500 million to five billion per gram. Generally, five or ten grams of powder is sufficient for the inoculation of 100 pounds of cheese curd.

The Role of Microorganisms. Although several types of microorganisms may be present in blue-veined cheese, only two are essential for manufacture, ripening and flavor development. These organisms are *Streptococcus lactis* and *Penicillium roqueforti*.

Streptococcus lactis is a bacterium which is always present in raw milk and is characterized by its ability to ferment lactose rapidly with the production of lactic acid. This bacterium is of considerable importance during the manufacturing process. A small amount of lactic acid is beneficial from the standpoint of coagulation of milk with rennet. The rennin enzyme present in rennet coagulates milk in a short time in the presence of a slight quantity of acid. Growth of and acid production by *S. lactis* during the manufacturing procedure aid in removing moisture from the curd particles and in firming the curd. Also, by lowering the pH of the cheese a medium is provided which is unfavorable for the growth of many other bacteria. The lactic acid-producing streptococci complete their role in a short time, and analyses indicate that viable organisms of this group have largely disappeared from the cheese shortly after salting or after about ten days.

Penicillium roqueforti is a mold which produces both proteolytic and lipolytic enzymes. Also, the mold is capable of growing in a low oxygen tension and in the presence of considerable sodium chloride. These characteristics make the mold ideally suited for Roquefort-type cheese. The action of *P. roqueforti* may be observed soon after the cheese are manufactured. Frequently, the day following manufacture a slight odor of methyl-*n*-amyl ketone is evident. Visible spore formation by *P. roqueforti* can be observed eight or ten days after manufacture. Fat hydrolysis by the natural milk lipase is evident during the manufacturing process but becomes more extensive after growth of *P. roqueforti* in the cheese. When mold becomes abundant in the cheese, the texture of the cheese becomes softer due to the production of a protease by *P. roqueforti*. The protease produced by mold, however, is not solely responsible for the decomposition of casein, since rennet as well as *S. lactis* can bring about appreciable breakdown. However, of the various proteases, that produced by *P. roqueforti* is perhaps the most important. Therefore, *P. roqueforti* contributes to protein degradation as well as to flavor production in blue-veined cheeses.

Flavor. Considerable research has been conducted to determine the compounds responsible for the flavor of blue-veined cheese. This flavor has been described by various individuals as sharp, peppery, pungent, burning, piquant, etc.

Orla-Jensen (15) stated that the chief constituent responsible for the flavor and aroma of Roquefort cheese is ethyl

butyrate. Currie (4) was of the opinion that the accumulation in the cheese of caproic, caprylic and capric acids with their easily hydrolyzable salts are responsible, in large part, for the peppery taste and burning effect of Roquefort cheese. Also, Currie (5) noted that Blue cheese made from sheep's milk had

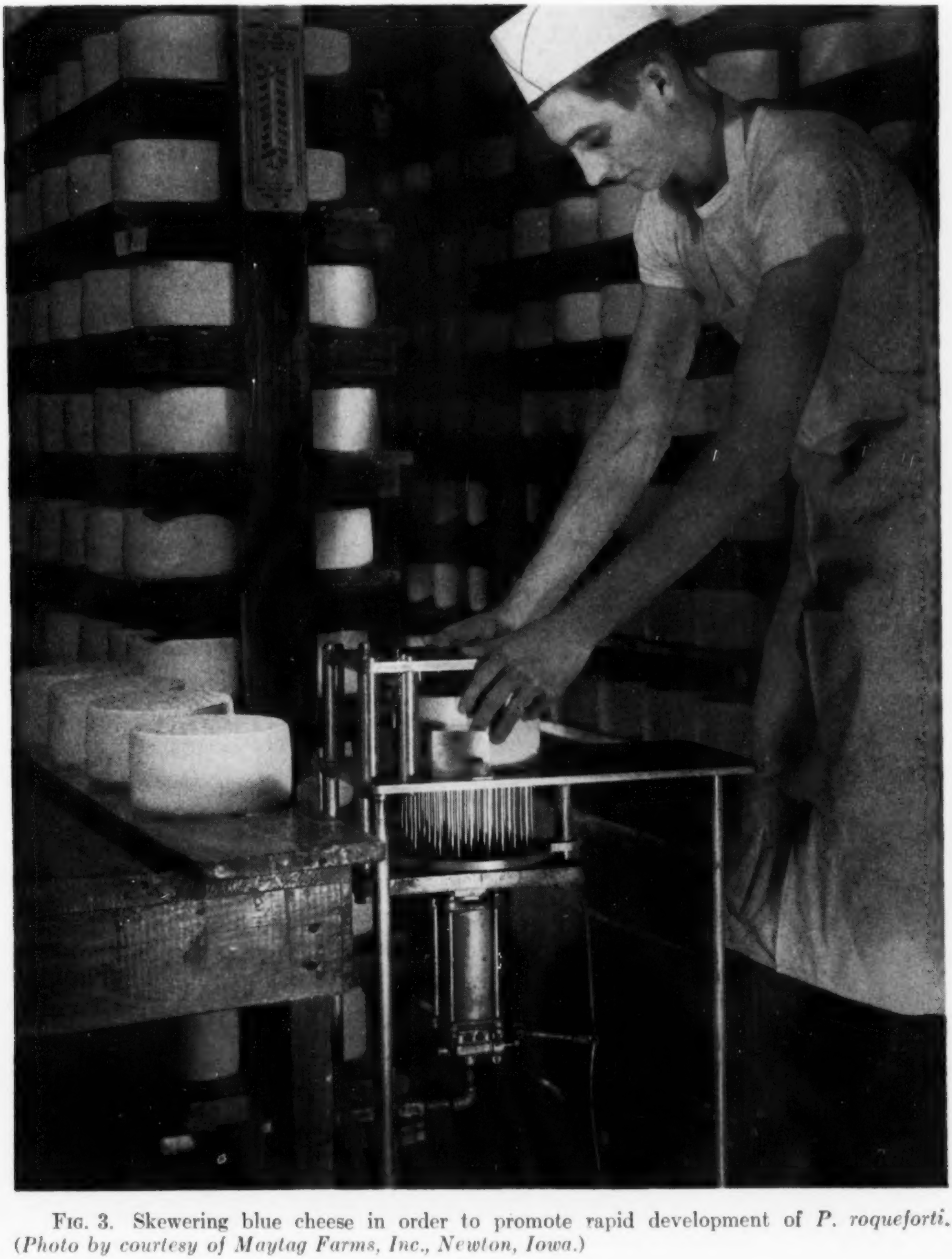


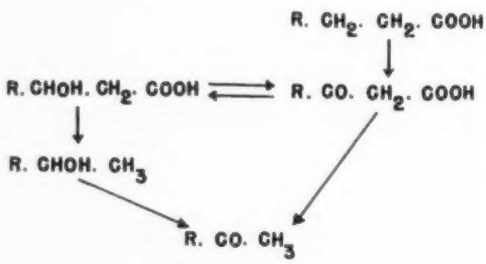
FIG. 3. Skewering blue cheese in order to promote rapid development of *P. roqueforti*. (*Photo by courtesy of Maytag Farms, Inc., Newton, Iowa.*)

more of the peppery taste than cheese of the same ripeness made from cow's milk.

Stärkle (17) studied the methyl ketones in the oxidative decomposition of certain triglycerides and fatty acids from the standpoint of rancidity of coconut fat. He considered the methyl ketones as possibly important in the rancidity of butter and in Roquefort cheese. Stärkle expressed the opinion that the characteristic aroma materials in the ripening of cheese by molds are, in the case of Roquefort, methyl ketones instead of esters. When he distilled Roquefort, about two drops of material was obtained which had an intensive odor of methyl-amyl and methyl-heptyl ketones. The amount was too small to permit separation and identification.

Bryant (1) demonstrated that *P. roqueforti* utilizes various fatty acids. When known amounts of fatty acids were added to a medium inoculated with *P. roqueforti*, there was reduction of the acids. The reduction was greatest with butyric acid and decreased as the molecular weight of the acids increased. Hammer and Bryant (9) stated that fatty acids alone do not account for the flavor of Blue cheese. These investigators added various fatty acids plus spores of *P. roqueforti* to sterile milk. A flask containing *n*-caprylic acid was of special interest. When held for several days at room temperature, no mold growth appeared at the surface, but the peppery odor of blue cheese was noted. Later, mold growth developed and the flavor disappeared. The odorous compound produced in milk with caprylic acid and mold spores added could be removed from milk by steam distillation. Also, the odorous compound could be removed from the distillate by shaking with ethyl ether. After evaporating the ether, the residue gave a ketone reaction. Various tests conducted on the residue led to the conclusion that the material was largely methyl-*n*-amyl ketone.

Stokoe (18) explains the formation of methyl ketones from fatty acids by molds as follows:



Recently, Patton (16) studied the methyl ketones of Blue cheese and their relation to its flavor. By means of a steam distillation and ether extraction procedure he was able to recover material from Blue cheese containing a high concentration of methyl ketones. Fractional distillation of this material gave relatively pure fractions of methyl-propyl, methyl-amyl and methyl-heptyl ketones. The methyl ketones appeared to be formed in the cheese by beta-oxidation of fatty acids to the beta-hydroxy acids and then to the beta-keto acids which are decarboxylated to form methyl ketones and carbon dioxide, according to the scheme outlined by Stokoe (18).

Influence of Certain Steps in the Manufacturing Procedure on the Activity of Fungi, Bacteria and Enzymes. Blue-veined cheese of the Roquefort type are produced largely from raw homogenized milk. When pasteurized milk is employed in manufacture, the natural milk lipase is destroyed and the resulting cheese require a longer period to attain a particular degree of flavor, even though homogenized-pasteurized milk may be employed. The effect of pasteurization is clearly brought out by the data in Table I.

Table I also shows the desirable effect of homogenization in bringing about in-

creased fat hydrolysis. From these data it is evident that increasing the fat surface by homogenization is more important in fat hydrolysis of Blue cheese than the presence of the natural milk lipase. However, the use of raw milk plus homogenization produces a very definite increase in fat hydrolysis when compared to either raw non-homogenized or pasteurized-homogenized milk. It is quite difficult to assess the relative importance of milk lipase and lipase produced by *P. roqueforti* with regard to their ability to hydrolyze fat. Mold development in cheese varies to some extent and greatly influences fat hydrolysis.

The practice of separating milk and of homogenizing the cream obtained from it rather than homogenizing the milk itself is followed because of a saving in time, a smaller sized homogenizer can be used, and the procedure is more adaptable to the bleaching operation. If 100 pounds of milk containing 3.5 percent fat is separated into skimmilk and cream containing 35 percent fat, only ten pounds of cream must be homogenized. When fat is bleached with benzoyl peroxide in order to produce white cheese, the temperature at which bleaching is carried out is often greater than the temperature required to destroy the natural milk lipase. The milk lipase is largely in the skimmilk portion when milk is separated. Therefore, the cream may be heated to temperatures which destroy milk lipase without affecting its activity in cheese appreciably.

The culture of lactic acid-producing streptococci added to the milk intended for cheese manufacture contains about 0.75 percent lactic acid. The small amount of lactic acid added by the culture plus a small amount of lactic acid produced by the culture during the ripening period greatly assists in the coagulation of milk by rennet. Ripening is carried out at 90° F because it is near the optimum growth temperature of the lactic acid-producing bacteria. The entire cheese-making operation is conducted at 90° F because growth and acid production by the lactic culture must be maintained. Production of acid also assists in the removal of moisture from the curd particles and lowers the pH to a point that is unfavorable for the growth of many microorganisms. However, development of too much acid during manufacture is not conducive to good quality cheese.

One of the most important factors in the production of good quality cheese is the ability of the cheesemaker to obtain a firm curd without an excessively high whey acidity. Acid favors fusion of the curd particles, and if the cheese have few mechanical openings in the interior, the mold will not be able to spread through it. Cheese with few mechanical openings shows little mold development and consequently will not ripen in a

TABLE I

EFFECT OF PASTEURIZING AND THEN HOMOGENIZING THE MILK INTENDED FOR CHEESEMAKING ON THE AMOUNT AND GENERAL TYPES OF VOLATILE ACID, THE ACID VALUE OF THE FAT, AND THE FLAVOR OF BLUE CHEESE (13).

Type of milk used	Age of cheese	Ml. N/10 volatile acids per 200 g. cheese	Acid No. of fat	Flavor
Raw	12 weeks	9.0	13.2	Poor, musty, bitter
Raw-homogenized	12 "	32.0	63.0	Good
Pasteurized-homogenized	12 "	15.0	27.6	Lacking in flavor

short period of time. Both flavor and texture will be influenced by the lack of mold growth.

The salt and oxygen content of Roquefort-type cheese are very important in controlling the growth of fungi other than *P. roqueforti*. The presence of four percent salt and a low oxygen tension inhibit the growth of all fungi except *P. roqueforti* or very similar species. *Oospora lactis*, the common mold associated with milk and cream, is one of the few molds capable of growing in a low oxygen tension, but it is inhibited by the salt concentration. If a cheese contains four percent salt and 40 percent moisture, the concentration of salt in the aqueous portion is ten percent. Some openings must be made in the cheese to permit satisfactory growth of *P. roqueforti*. This is accomplished by piercing the cheese with needles, and the process is known as skewering. Golding (6) presents data to show that the purpose of skewering blue-veined cheese is to allow carbon dioxide to escape rather than to permit entrance of air. If cheese are punched with needles having too great a diameter, the oxygen content in the punched areas will be great enough to permit the development of fungi other than *P. roqueforti*.

Defects Due to Fungi. Some manufacturers of Blue cheese have experienced considerable difficulty with red areas of mold growth on the surface during the ripening period or during the storage period. Red mold is very conspicuous on Blue cheese and first becomes evident as small bright red colonies which may be few or very numerous. In some cases the red mold is noted in about ten days. It appears on the surface and is important only because of its color. Hammer and Gilman (10) identified it as *Sporendonema casei* and suggested use of petrolatum containing added calcium propionate or propionic acid for coating the cheese and thus preventing development of the mold. At the present time the method employed for limiting growth of the mold consists of coating the cheese with a flexible cheese coating. The cheese can be punched (skewered) after a suitable coating has been applied.

When Blue cheese are punched with needles that are too large in diameter, molds other than *P. roqueforti* may invade through the punch holes. In some cheese-manufacturing plants, a black discoloration of cheese accompanied by a musty flavor has been noted. This defect originates at the area of the punch hole and often spreads through the interior of the cheese. Bryant and Hammer (2) studied the black-discoloration defect and found that it was caused by *Hormodendrum olivaceum*. Their studies indicated that the mold required a good oxygen supply for growth and therefore would not produce defective cheese if the cheese were manufactured properly.

A gray discoloration is sometimes noted in Blue cheese, particularly in cheese that are ripened for very long periods. The discoloration is first noted on the surface and gradually spreads toward the interior, accompanied by a mousy ammoniacal flavor which later becomes soapy. Bryant and Hammer (2) thought that the gray discoloration might be due to the action of certain forms of *Actinomyces* because of their tendency to darken media containing tyrosine. Also, certain cheese discolorations have been attributed to melanins produced by the action of tyrosinase upon tyrosine. The gray discoloration could not be produced by addition of *Actinomyces* cultures to cheese curd made into Blue cheese. Presumably the organisms failed to grow in the cheese.

Camembert Cheese

Camembert cheese had its origin in France about the time of Napoleon.

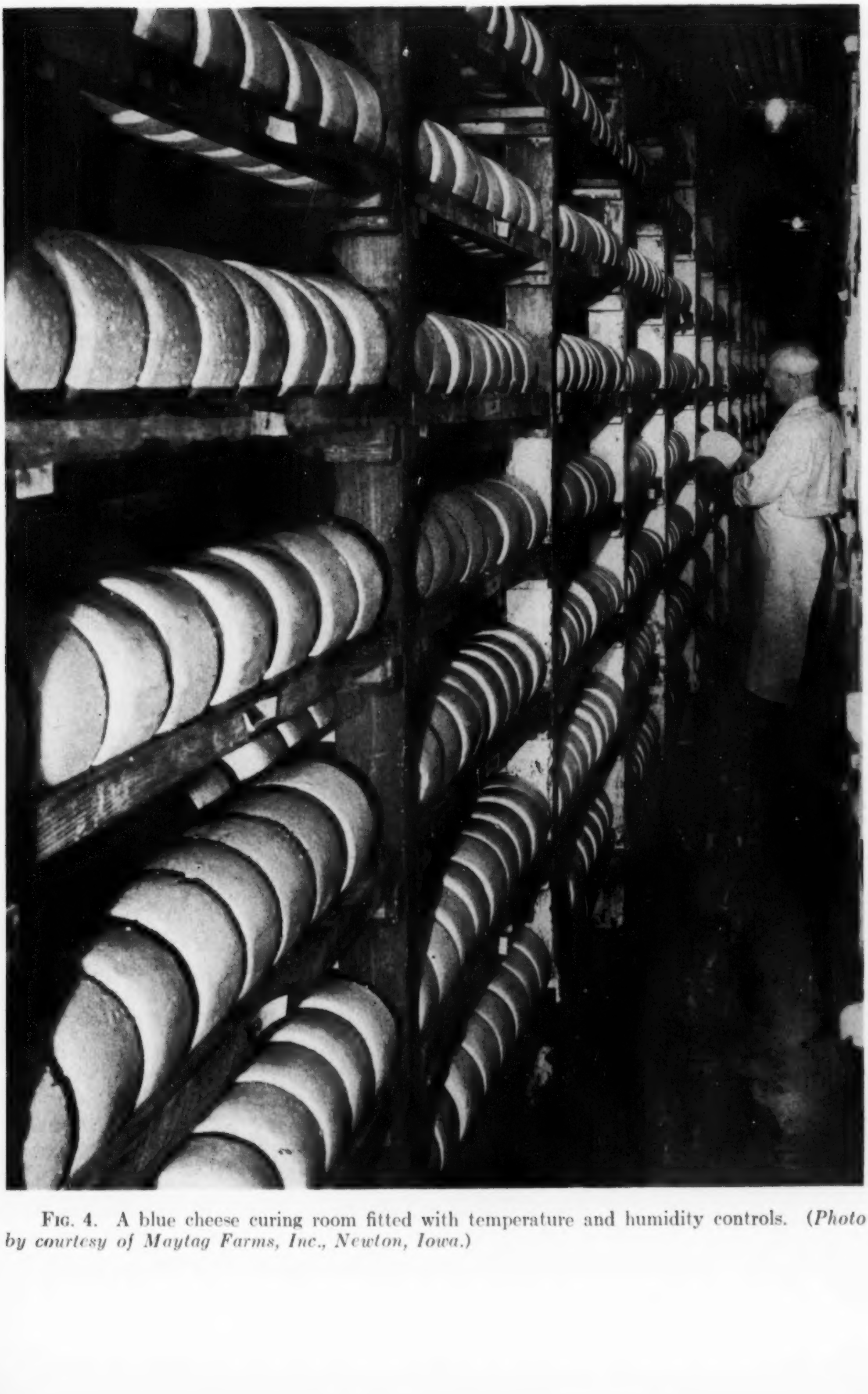


FIG. 4. A blue cheese curing room fitted with temperature and humidity controls. (*Photo by courtesy of Maytag Farms, Inc., Newton, Iowa.*)

Some of the cheese was exported to the United States where it found a select market. About 1900, various cheese manufacturers and research organizations in this country became interested in Camembert. Much of the pioneer work with regard to the development of manufacturing procedures and studies on the chemistry and microbiology of it was conducted jointly by the Storrs Agricultural Experiment Station, Storrs, Conn., and the United States Department of Agriculture. The first research work on Camembert cheese in the United States was started about 1904. Shortly after this time, several commercial companies began manufacturing the cheese. Previous to 1920 a considerable portion of the amount consumed in the United States was imported from France, but at the present time, practically all of this type cheese in the United States is of domestic manufacture.

Manufacturing Procedure. Pasteurized milk containing 3.5 to 3.7 percent butterfat is adjusted to a temperature of 86° F, and two percent of an active culture of lactic acid-producing streptococci is added. The milk is held at 86° F about one hour to permit formation of lactic acid by the bacterial culture. After the ripening period the milk is curdled by addition of rennet extract which is added at the rate of three and one-half to four ounces per 1000 pounds of milk. The milk generally coagulates in 12 to 14 minutes, but it is allowed to remain undisturbed for about one hour to permit formation of acid and a desirable curd texture. After the setting period the curd is cut into cubes of about one-quarter inch by means of curd knives. The cut curd is not disturbed for about 15 minutes after cutting, and then it is gently stirred for about one hour to permit the curd to firm and the

FIG. 5 (*Upper*). Man-made cave for the storage of blue cheese. (*Photo by courtesy of Treasure Cave Cheese Company, Faribault, Minn.*)

FIG. 6 (*Lower*). A natural blue cheese curing room made by tunneling into a hill of St. Peter's sandstone. (*Photo by courtesy of Treasure Cave Cheese Company, Faribault, Minn.*)

acidity to increase. The vat contents are held at 84° to 86° F throughout the entire manufacturing operation. When the curd is sufficiently firm, a portion of the whey is drained and the curd is dipped into forms. The forms consist of perforated cylinders five inches in diameter and five inches high. Before dipping the curd, the forms are placed on reed mats about 15 inches square. The mats provide a surface which permits whey to escape and thus facilitates drainage. The cheese are turned in the hoops regularly after dipping to provide uniform drainage and regular shape. Eighteen to 20 hours after dipping, the cheese are removed from the hoops and taken to the salting room. The cheese are surface salted so as to contain approximately two and one-half percent salt. Following salting, the cheese are placed in the ripening room which is maintained at 56° to 58° F and a relative humidity of about 90 percent. During the ripening period the cheese are turned frequently to assure even distribution of mold. After ripening for ten to 14 days, the cheese are cut into wedge-shaped portions and wrapped in foil.

Preparation of Mold. The usual method of culturing mold for use in inoculating Camembert cheese is to grow the mold on water crackers. Water crackers are placed in a wide-mouth container and sterilized by means of steam under pressure. After sterilization the crackers are moistened with sterile water and inoculated with a culture of *Penicillium camemberti* taken from an agar slant. The containers, filled about two-thirds with crackers, are incubated at 60° F until the crackers become covered with mold. The cheese are inoculated by sprinkling or spraying with a suspension of the mold spores. Inoculation of the cheese with mold is generally done immediately after taking the cheese from the hoops, although

FIG. 7. *Penicillium camemberti* grown on Czapeks agar.

some manufacturers prefer to inoculate the cheese during or after the salting. Both methods have given satisfactory results.

Role of Bacteria and Fungi. During the manufacture of Camembert cheese, the lactic acid-producing streptococci are important from the standpoint of acid production only and perform the same general function in Camembert as they do in blue-veined cheese. Acidity produced by these bacteria is necessary for curdling, whey drainage and properly textured curd. The lactic acid bacteria find conditions for growth very satisfactory during the manufacturing operation, and conditions are adjusted so that the organisms will grow rapidly. Large numbers of these bacteria are present in the interior of the cheese throughout the ripening period.

Some factories manufacturing Camembert cheese believe that the organism *Bacterium linens* is essential to the manufacture of good quality product, and the organism is added to the cheese milk or to the cheese surface after manufacture. *B. linens* requires considerable oxygen for growth and therefore appears only on the cheese surface. The organism is very salt-tolerant also and thus finds the cheese surface an ideal medium for growth. The exact role played by *B. linens* in the ripening process is not fully understood. It is known that this bacterium can neutralize the acidity at the surface and may assist the action of proteolytic enzymes which act more rapidly at a neutral or slight alkaline reaction. Most cheese will contain this organism on the surface, even though a culture is not added. In some cases the organism is not noted until late in the ripening period pecause of the early and rapid growth of *P. camemberti*. *B. linens* produces a reddish cast, and if the humidity of the ripening room is excessively high it will form a definite reddish slime on the cheese.

The important ripening agent of Camembert cheese is *P. camemberti*. This mold requires considerable oxygen for growth and is present on the cheese surface. The mold mycelium does not penetrate the cheese. *P. camemberti* is quite salt-tolerant. The mycelium of the mold is visible on the cheese surface about four days after manufacture, and the surface shows a trace of gray color due to the production of spores after about ten days. *P. camemberti* produces an active proteolytic enzyme which is largely responsible for cheese ripening. Although mold growth is confined to the surface, the proteolytic enzymes produced by the mold find their way to the interior of the cheese. Because of surface ripening, either Camembert or Brie cheese are manufactured so as to have a thickness of one to one and one-fourth inches. Thickness of the cheese is important because it is essential that the entire cheese be ripened uniformly. If a thicker cheese were inoculated with *P. camemberti*, its surface would be digested to a watery consistency, while the center would remain hard.

In the early studies on Camembert (19) it was believed that *Oospora lactis* was responsible for the flavor of the cheese. If *O. lactis* is present on the cheese surface it generally grows slowly during the early part of the ripening, due to the high salt concentration. However, it finds conditions suitable for growth late in the ripening period or at about the time that the cheese acquires typical flavor.

Defects. Since Camembert cheese is manufactured from pasteurized milk, many microorganisms capable of producing defects are destroyed by the pasteurization process if it is carried out properly. Certain defects may result from improper manufacturing procedures or from failure of the lactic acid-producing bacteria to form acid. However, the principal defects encountered

are due largely to contaminants on the surface. Growth of the white mold *P. camemberti* on the surface is very evident and is expected by the consumer. Contamination by blue-green molds, black molds, etc., presents an unsightly surface, and such contaminants are eliminated by proper cleaning and sanitizing methods in the cheese plant and in the curing rooms. Manufacturers of Camembert cheese prefer to use several small curing rooms rather than a large one so that the rooms can be emptied and cleaned before refilling with fresh cheese. Yeast contamination on the surface may result in the production of cheese with a yeasty flavor. Pink yeasts are particularly objectionable because they are readily visible on the surface.

With many cheese varieties, a long ripening period is quite desirable from the standpoint of flavor development and protein degradation. Camembert or Brie cheese cannot be ripened for extended periods and must be marketed in a rather short time. Extended ripening results in a cheese with too much protein decomposition and this is brought about by the protease of *P. camemberti.*

Summary

Fungi are necessary for the manufacture of two general types of cheese—blue-veined cheeses (Roquefort, Gorgonzola, Stilton and Blue); and Camembert and Brie cheese.

The important mold in blue-veined cheeses is *Penicillium roqueforti* or a very similar species. This mold tolerates considerable sodium chloride and will grow in a low oxygen tension. *P. roqueforti* produces a lipase which is important in contributing to the characteristic flavor of blue-veined cheeses and also produces a protease which aids in protein decomposition or in the production of cheese with a buttery texture.

The important mold on Camembert or Brie cheese is *Penicillium camemberti.* This mold grows well on the surface of cheese containing 2.5 percent sodium chloride. *P. camemberti* produces a very active protease which penetrates cheese and which is responsible for the extensive protein degradation of Camembert or Brie.

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Utilization Abstract

Violet Perfumes. The Parma violet, a cultivated form of *Viola odorata semperflorens*, is the most important source of violet perfume manufactured in France, where more than 30 species are native. " It is most at home in the regions of Grasse and Toulouse in France and in the Taggia Valley in Italy. The violets which are used in perfumery come mostly from Grasse; those from the other districts are principally used to make up bouquets. In 1865 Vence and its surroundings produced 80,000 kilograms of Parma flowers for perfumery purposes. Around 1870 the cultivation had spread to Le Bar, Tourettes, and Peimeynado ".

" The violets which grow through the loose ground surrounding trees are more fragrant than those which are exposed to the open sun. For this reason, the plantations in the surroundings of Grasse are protected by olive trees and orange trees. Violets must also be protected from fresh winds and the rigors of wintertime, as these may retard the flowering or even kill the plant. In the plains of Hyères brier branches and in Italy straw mats are used as cover, and around Toulouse glass-covered frames form the protection ".

" The time of planting varies according to the district and method of cultivation. In the dry climate of the Provence it must not be undertaken later than March–April; the best months are December and January. During planting, as well as during summertime, the ground has to be sufficiently watered. Besides this, it has to be ploughed and weeded. During picking time, the flowering has to be sustained by applying liquid manure ".

" The violets begin to flower right during the first year after planting. The picking of flowers for bouquets starts during October–November, while the flowers to be used for perfume are gathered from January to April. Picking is done either in the morning, after the dew has fallen, or at night. This kind of harvesting takes much time and is costly, as the flowers have to be ' cut ', one after the other, with the nail. A woman is able to collect three to six kilograms per day, according to ability and abundance of flowers. One kilogram has about 4000 flowers ".

" The flowers have to be processed as soon as they are picked, if one wants to have a perfume which has not lost anything of its delicacy and its freshness. The violets are processed either by heat-method maceration in fat, or cold-method maceration in oil. However, the most common way of processing is by means of volatile dissolvants which make it possible to obtain a strong concentration within a very small space. Results vary according to the method used. About 1100 to 1200 kilograms of Parma violets must be treated in order to obtain one kilogram of the final product ".

The Victoria variety, which is used in bouquets and at the end of the season in the factories around Grasse, is planted in the districts of Hyères, Solliès, Ollioules and Var, and on the Italian Riviera. The most popular variety for bouquets, however, is La Luxonne; two others for the purpose are Princess of Wales and The Czar. From 1400 to 1500 kilograms of Victoria violets are needed for one kilogram of perfume. (A. J. Hughes, *Am. Perf. & Ess. Oil Rev. 60: 105. 1952*).

Production, Harvesting, Processing, Utilization and Economic Importance of Oats[1]

Oats constitute an important feed grain crop in the United States and many other countries. World production in pounds averages one-third that of wheat and two-fifths that of rice or corn. The United States and Canada produce nearly half of the world crop. Oats are utilized primarily as feed for domestic animals. Although their bone- and muscle-building ingredients and other nutrient values are well known, less than five percent of the world crop is used as human food.

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World Distribution

Oats are the fourth most important cereal crop of the world, production usually slightly exceeding four billion bushels annually. In total pounds produced, wheat, rice, corn and oats rank in the order named.

Oats are widely distributed in the temperate zones of the world. The five leading countries in oat production are the United States, Russia, Canada, Germany and France with approximate annual productions of 1,300 million, 760 million, 445 million, 300 million and 250 million bushels, respectively. These countries produce about three-fourths of the world's total annual crop.

Oats are of relatively limited interest in grain markets because much of the grain is fed on the home farm and less than five percent of the world crop is processed into food. Oats constitute an important and valuable feed for all classes of livestock, particularly horses, dairy cows, poultry, and young and breeding animals of all kinds. Oats are high in protein, fat, vitamin B_1 and minerals such as phosphorus and iron.

Natural Factors Influencing Production

Oat culture flourishes best in cool moist regions such as the northern

United States, southern Canada and northern Europe. The important natural factors influencing the development and growth of the oat plant in any region are rainfall, temperature, soil productivity, diseases and insects. Weather is the most important.

The leading oat-producing areas are in the more humid portions of the world, as the oat plant requires more water for its best development than any other small grain. Hot dry weather when the grain is developing often causes premature ripening, whereas hot humid weather during this period favors development of diseases that frequently markedly reduce yield and quality.

Winterkilling sometimes causes serious reduction in stand and yield where oats are sown in the fall. In recent years the distribution of hardier or more cold-resistant varieties of winter oats, such as Fulwin, Forkedeer and Wintok, has reduced losses from freezing and thus made the crop a more certain one in the more northern parts of the winter oat region of southern United States. Research to advance the winter oat belt northward through the breeding of hardier varieties should be expanded. This should include determination of the factors that contribute to winter-hardiness. Fall-sown oats have many advantages over spring-sown oats wherever they can be grown successfully. They provide a soil cover and much valuable grazing during fall and winter. They mature earlier than do spring-sown oats and thus escape to some extent infection by rusts and other diseases, and usually mature before the advent of hot summer weather. Hence winter oats where adapted produce higher acre yields of better quality grain than do spring oats. Another advantage is the earlier removal of oats from the land, thus enabling earlier and more timely planting of the crop that is to follow. Also a better dis-

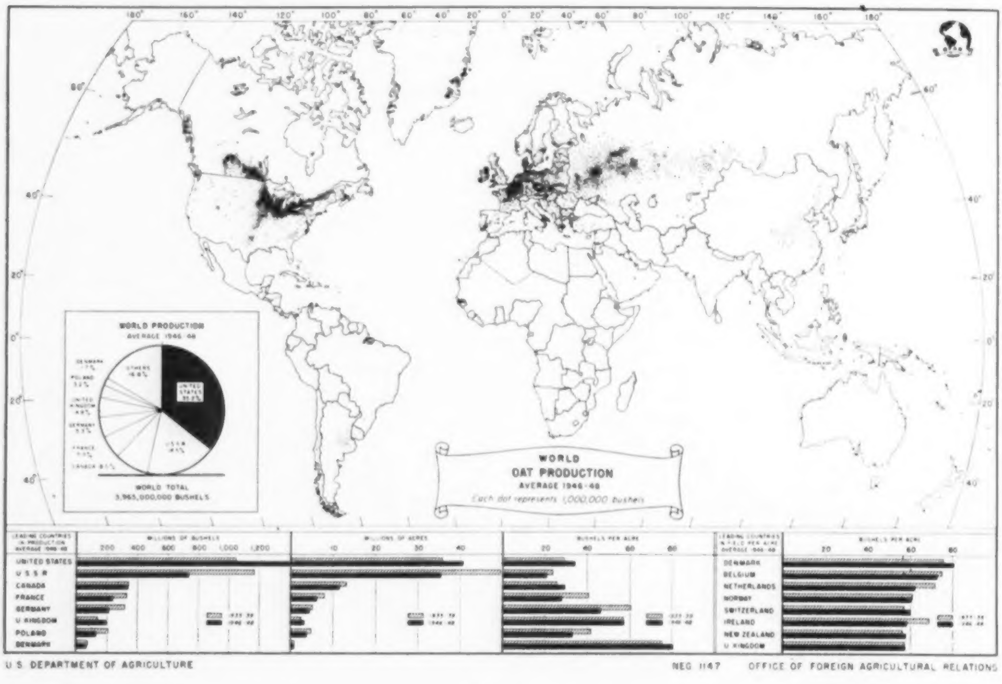

Fig. 1.

tribution of farm labor is obtained by sowing the crop in the fall.

The most serious diseases of oats are caused by the rusts, smuts and foot rots. Other diseases include *Helminthosporium* blights, Septoria black stem, mildew, viruses (mosaics) and anthracnose. In England the so-called gray-speck disease is common on oats, due primarily to a deficiency of manganese in the soil. This trouble, however, is easily corrected by application of manganese to the soil. Rusts have been especially destructive in the United States, but in the last decade losses have been greatly reduced by the distribution of improved disease-resistant varieties. The oat smuts have been common but less destructive than the rusts. During the past decade losses from these diseases have been reduced to a minimum by the distribution of resistant varieties and also by a much wider and more intensive use of new and efficient fungicides, such as New Improved Ceresan and Ceresan M for control through seed treatment. From 1945 to 1947 heavy losses were caused by Victoria blight (*Helminthosporium victoriae* Meehan and Murphy), then a new and very destructive disease, to be discussed more fully later. Fortunately this disease was quickly controlled by distribution of varieties carrying resistant germ plasm derived from Bond oats, and by the end of the 1951 harvest it had almost completely disappeared in most sections. *Helminthosporium avenae*, *Pythium debaryanum* and other foot rot troubles have caused losses in some sections in certain years, although usually considered in the category of minor diseases. The losses from these diseases may be greater than is generally believed, but they are difficult to measure.

Fortunately the growing oat crop is relatively free from insect pests except for the periodic attacks of the green bug or plant aphid in the central and south central States. Infestations of the green bug have been unusually abundant in recent years. Attempts are being made to discover or breed varieties resistant to green-bug injury, but results obtained so far have not been especially encouraging. The frit fly is a common pest of oats in England, but has been controlled by the distribution of resistant varieties.

Chinch bugs and various stem borers, which are so destructive to other grain crops, cause little damage to oats.

Importance of Oats in the United States

Oats rank third among the cereal crops of the United States. They are grown on around 40 million acres annually. Oats have held their place in the agriculture of the United States not as a cash crop but because of their high-feeding value, their usefulness in crop rotations, and the economy of labor in producing and handling the crop. Frequently plowing is not necessary in preparing the seedbed because oats follow corn or other row crops. The use of oats as a companion crop for clover and grass seedings is exceedingly valuable. The sowing of oats on cornland in the Corn Belt utilizes labor that might otherwise be unproductive.

For many years low acre returns from the oat crop and the passing of the horse made oats the common " whipping boy " of the agricultural economist. A recommended reduction in the acreage of oats was a perennial feature of farm outlook reports. Oat production declined in the 1930's, owing to low yield and quality, and there was some justification for the belief that the crop was deteriorating. However, during the last decade the economic status of oats was greatly improved by the distribution of disease-resistant and more productive new varieties. Thus a more consistently higher yield of better quality oats made the crop more popular.

Origin of the Oat Plant

As is the case with most cultivated crops, the origin of cultivated oats is clouded with obscurity. Mal'tzev [3], a modern Russian systematist, indicates that there is no definite record to lead botanists to believe that oats were known to the ancient Chinese, Hebrews or Hindus. The writers of classical antiquity—Cato, Cicero, Theophrastus, Ovid, Varro—appear to refer to oats only as a weed which was used for medicinal purposes.

The common oat, decidedly the one most important of all the cultivated and botanical forms of *Avena*, appears to have been first found growing in different regions of western Europe, whence it spread to various parts of the world, especially into regions having a favorable environment for its growth and culture. It may have been first grown by the ancient Slavonic peoples who inhabited western Europe during the Iron and Bronze Ages. Mal'tzev also believes that this group of oats, belonging to the cycle *Avena fatua* (wild oats), the generally accepted progenitor of *A. sativa* (common oat), is of Asiatic origin.

The first authentic historical notes on cultivated oats appear at the beginning of the Christian era. The writings of Columella, Dioscorides, Pliny and other historical writers of the early Christian era indicate that the common oat (*Avena sativa*) was grown by Europeans for grain and the red oat (*A. byzantina*) for forage, particularly in Asia Minor. Thus the most authentic information available indicates that the cultivated red oat of the southern United States, South America, Australia, the Mediterranean region of Europe and other regions with similar warm climates, had a common origin in Asia Minor, or west of the Mediterranean. Furthermore, since the red oat apparently has not been found anywhere in ancient excavations, it is considered to be of more recent origin than the common oat. However, evidence published fairly recently [4] indicates that this may not be true. The theory is advanced that the common oat originated from the red oat and hence that the latter would be the older species.

Among the early writers of the Christian era the belief obtained that oats probably were first found as a weed which infested fields of barley. As a consequence, oats may have been first widely distributed as a mixture in barley and later selected and domesticated. The fact that Harlan [5] found oats of the minor species, *Avena abyssinica*, growing wild only as a weed in barley in Ethiopia would lend credence to this belief.

Oats apparently were first brought to America, along with wheat, barley and rye, by Captain Gosnold who grew these grains on one of the Elizabeth Islands off the southern coast of Massachusetts in 1602. In Virginia the first oats probably were tried as early as 1611 at the time wheat was first sown by the Jamestown colony. However, due to poorly adapted varieties, primitive cultural methods, a somewhat unfavorable climate and a lack of the "know how" for growing these crops, neither wheat nor oats appears to have been grown successfully by the first colonists of the Atlantic coast, although they were grown with some success at a later date.

Botany of the Oat Plant

The genus *Avena* apparently was established in the year 1700 by Tournefort, a French explorer and botanist. Most spe-

[3] Mal'tzev, A. I. Wild and cultivated oats, sectio euavena Griseb. Bull. Appl. Bot., Genet. & Plant Breed., Sup. 522 pp. 1930. [Text and additional title and summary in Russian].

[4] Coffman, F. A. Origin of cultivated oats. Jour. Am. Soc. Agron. 38: 983–1002. 1946.

[5] Stanton, T. R., and Dorsey, E. Morphological and cytological studies of an oat from Ethiopia. Jour. Am. Soc. Agron. 19: 804–818. 1927.

FIG. 2. Panicles, spikelets, and florets of oats: (A) Equilateral (spreading or tree type) panicle; (B) unilateral (side or horsemane) panicle; (C) common oats (*Avena sativa* L.); (D) red oats (*A. byzantina* C. Koch); (E) long grains; (F) short grains; (G) plump grains; (H) slender grains; (I) hull-less or naked oats; (J) wild oats (*A. fatua* L.); and (K) wild red oats (*A. sterilis* L.).

cies of oats known today were first described as early as 1750 by Linnaeus, the great Swedish botanist who lived at Uppsala, Sweden, and who has now come to be regarded as the father of modern systematic botany.

The common oat (*Avena sativa*) is grown in the cooler and more temperate regions of the world and includes the bulk of oats produced today. The red oat is grown mainly in regions considered too warm for the best growth of the common oat. If it were not for these heat-tolerant red oat varieties, oat production would be much less important in the southern United States, South America, Australia and the Mediterranean countries of Europe.

The writer[6] published a description of the oat plant which is quoted as follows:

"The oat plant is an annual grass belonging to the genus *Avena*. Cultivated oats are derived chiefly from two species, the common wild oat (*A. fatua* L.) and the wild red (*A. sterilis* L.). The principal derivatives of the former are the common oat (*A. sativa* L.), including the side oat (*A. orientalis* Schreb.). Of the latter, the only important cultivated form is *A. byzantina* (C. Koch), including *A. sterilis algeriensis* Trabut". Panicles, spikelets and florets of these groups are shown in Fig. 2.

Under average conditions the oat plant produces from three to five hollow stems, or culms, varying from one-eighth to one-fourth inch in diameter and from two to five feet in height. The roots are small, numerous and fibrous, and penetrate the soil to a depth of several feet. The leaves average about ten inches in length and five-eighths of an inch in width. The panicles, or heads, are either spreading (equilateral, or tree-like) or one-sided (unilateral, horse-mane, or banner-like). By far the greater number of cultivated varieties have spreading panicles. The grain is produced on small branches, in spikelets, varying in number from 20 to 150 per panicle. Each spikelet contains two or three florets or grains except those of the hull-less or naked oat which contain four to eight. The spikelet is loosely enclosed within the outer glumes (chaff). The kernels, except in the hull-less oat, are tightly enclosed within the lemmas or inner glumes and palea. The lemma or hull ranges in color from white, yellow, gray and red to black, and may be awned or awnless. The kernel, or more properly the caryopsis, without its adhering glumes, is very slender, ranging from five- to seven-sixteenths of an inch in length and from one- to two-sixteenths of an inch in width. The kernel constitutes 65 to 75 percent of the total weight of the whole grain.

Oat Breeding

Three methods of oat improvement have been used in the United States as well as in most other oat-producing countries, viz., introduction, selection and hybridization. The first method was employed by immigrants who brought to America seed of the varieties commonly grown in their native Provinces or States of the Old World. During much of the 19th century Federal government officials also introduced many new varieties into the United States that were distributed to farmers.

Improvement by selection started shortly after the turn of the century. It consisted of making and testing hundreds of panicle (head) or plant selections from old domestic and introduced varieties. The few lines that continued to be most promising in yield and quality usually were named and distributed to farmers as improved varieties.

Some of the older varieties that are

[6] Stanton, T. R. Superior germ plasm in oats. U. S. Dept. Agr. Yearbook **1937**: 347–414.

still grown on limited acreages originated in this manner. Victory, a variety widely grown in all northern oat-producing areas of the world, is the most classical example of improvement by selection. It originated as a pure-line selection made in Sweden from the old unselected Probsteier or Milton oat of the Baltic region of Europe. Other good examples are the Markton, Rainbow and Red Rustproof varieties. Markton, a well known smut-resistant oat grown in the Pacific Northwest States, was selected in Oregon from an unnamed mixed population designated only as Cereal Accession No. 357, introduced from Turkey. Rainbow, an important stem rust-resistant variety in North Dakota, also originated as a pure line from the old variety known as Green Russian. Another classical example of improvement by this method has been selection within the old Red Rustproof (Red Texas) variety that has been grown in the southern United States since 1875 or even earlier. A large number of named strains of this type of oats have been distributed, some of which have been grown or are being grown extensively today. Among these are Appler, Bancroft, California Red, Delta Red, Georgia Red Rustproof 14, Ferguson 922, Nortex and New Nortex.

The breeding of new varieties of oats by hybridization in the United States began in Vermont around 1870, but this method did not come into vogue in a large way until about 1920. Increased knowledge of genetics and plant pathology in the present century stimulated the cross breeding of oats. Hybridization provided a means of transferring rust, smut and other disease-resistant genes from inferior, poorly adapted varieties to superior, high-yielding economic types of oats.

Backcrossing is a modification of the straight cross-breeding method. Thus to transfer a desirable character, such as resistance to a particular race of the oat rusts, to a certain variety of oats, selected progenies from the original cross that carry the needed resistance are backcrossed to the original parent. Selection and backcrossing to the recurrent parent is repeated through three or more hybrid generations until the desired type is recovered. This method is being used more and more by oat breeders as its advantages become more fully appreciated.

There are many accessory procedures in oat breeding, especially in breeding for disease resistance. These include the development of artificial epidemics to infect and eliminate susceptible progenies, and the development, collection and application of the necessary inoculum.

Oat Genetics

The basic genetic principles determining the mode of inheritance of morphological characters and disease reactions in oats are the same as for wheat and barley. Most characters are inherited on a monogenic basis, including the 3:1 and 1:2:1 segregations. A relatively smaller number of characters are inherited on a digenic or trigenic basis, including the 15:1 and the 13:3 and 63:1 segregations. There remain many characters, mostly of a quantitative nature, that depend upon so-called multiple factors for their inheritance.

For a catalog of the characters in oats that are transmitted by these various types of inheritance, see Footnote 6, page 48, of this article.

Too Many Varieties

Several hundred varieties of oats may be differentiated by botanical characters, but the number of named commercial varieties runs into the thousands. The World Collection of Oats on file in the Division of Cereal Crops and Diseases, Plant Industry Station, U. S. Department of Agriculture, at Beltsville, Maryland, contains over 4000 varieties and strains.

Most of these are simply named or unnamed strains of a much smaller number of definite botanical types. During recent years the adoption by farmers of improved varieties recommended by State Agricultural Experiment Stations and Extension Services has greatly reduced the number of named, often nondescript, varieties that plagued the farmer 30 years ago.

Etheridge [7], in his classification of oat varieties, studied 731 collections and established 55 botanical varieties of red and common oats. The remaining strains were either classified as synonymous varieties or discarded as representing badly mixed or non-descript oats.

Marquand [8], an English botanist, in his classification of varieties of oats in cultivation, established 112 varieties and subvarieties of cultivated red and common oats. He also listed some synonymous varieties. In recent years the development and distribution of many improved disease-resistant varieties originating as selections from crosses between red and common oats has further complicated the varietal identification problem, owing to their great similarity in morphological characters and disease reactions.

Western Advance of Oat Production in the United States

Increase in the production of oats and their westward advance closely paralleled those of wheat. The growing of the crop began on the Atlantic seaboard early in the eighteenth century and was carried westward with the march of settlement and the agricultural development of fertile new areas and territories.

A marked shift westward in oat production occurred at the close of the Revolutionary War and continued to the middle of the eighteenth century. During this period production moved across the Appalachian Mountains into the Ohio River Valley and on into the great prairie region to the west. Expansion of oat production went hand in hand with the very rapid expansion of agriculture that took place from about 1870 to almost the end of the nineteenth century. As oat production advanced westward into less favorable areas, the average acre yields decreased. This was partly due to the use of late-maturing unadapted varieties that were subject to attacks of rust and other fungus diseases and to pioneer methods of agriculture. The greatest expansion, of course, took place in the Corn Belt with its millions of acres of continuous unbroken vast areas of arable, rich, virgin lands. During the period from around 1890 to about 1905 the area sown to oats expanded more slowly, and the acre yield increased with a corresponding increase in production.

Another period of rapid expansion in acreage began around 1906 and gradually increased until nearly 41 million acres were sown in 1915. Since that year the acreage of oats has remained more or less stationary, with the annual area fluctuating around 40 million acres. The high point was reached in 1946 when over 46 million acres were sown to oats and 1,535,676,000 bushels were produced. Production has approached a billion and half bushels in several recent years.

In the twenties there was a further shift westward to the newly developed agricultural lands of the western and southwestern United States. In the thirties there was some further expansion of oat production into the Gulf Coast region and south Texas. A greater expansion, however, occurred in these areas beginning about 1941, following the distribution of crown-rust-resistant

[7] Etheridge, W. C. A classification of the varieties of cultivated oats. N. Y. Cornell Agr. Exp. Sta., Mem. 10: 79–172. 1916.

[8] Marquand, C. V. B. Varieties of oats in cultivation. Univ. Col. of Wales, Welsh Plant Breeding Station, Series C, No. 2. 44 pp. 1922.

fall-sown varieties for both grain and grazing.

Before 1839 the growing of oats in the United States was confined almost entirely to the territory east of the Mississippi River. At that time more than half the oats were grown west of the Allegheny Mountains, the Ohio Valley having become a leading area of production, and oat culture was just beginning in southern Michigan and in Illinois.

By 1849 production had advanced slightly northward in Michigan and Wisconsin. The growing of oats spread rather generally over Missouri and had begun in southeastern Iowa. There also was some expansion southward.

Oat production continued its march westward from 1859 to 1889. Production began in California after the discovery of gold in that State in 1849 and soon started in western Oregon. Before 1859 rapid expansion had occurred northward into Michigan and Wisconsin, and westward into Iowa, and oat culture began in southeastern Minnesota and northeastern Texas. Coincident with a marked decline in the South, Illinois, Iowa and Wisconsin were rapidly becoming important States in oat production.

In the sixties the center of oat production shifted from the Ohio Valley to the Upper Mississippi Valley. Illinois replaced New York as the leading State in production. Production crossed the Missouri River into Nebraska and Kansas and also increased somewhat in the Pacific Coast States. The greatest expansion, however, took place in Illinois, Iowa, Wisconsin and Minnesota. There were no marked changes in the east.

In the seventies Iowa became important in oat production and pushed New York into third place. Production also expanded northward in Wisconsin and Minnesota. There was a slight resumption of oat production in Georgia and Alabama, and some expansion in northeastern Texas. Production in the Rocky Mountain and Great Basin States increased rather rapidly.

During the eighties total oat production in the United States was doubled. This great increase in production was due mostly to the enormous increase in acreage in Illinois and Iowa following a marked decline in spring-wheat production. These States had become decidedly the most important in oat production. The invention and development of the self-binder as an efficient implement of production contributed largely to the great increase in oat production during the decade, particularly on the expansive rich prairies of the Upper Mississippi Valley States.

No great expansion in production occurred during the nineties. This apparently was due to over-production and the extremely low farm prices which prevailed. The concentration of oat production in the States of the Upper Mississippi Valley, especially in Illinois and Iowa, with a corresponding development of railroad transportation, caused a slight decrease in production in the New England States, eastern New York, New Jersey and the South Atlantic States.

Total oat production in the United States in 1909, as in some previous years, exceeded a billion bushels. The expansion of oat culture in Minnesota, the Dakotas and more western States contributed largely to the increase in total production.

A second big increase in oat production occurred in the United States from 1910 to 1919 when the annual production of oats reached the enormous figure of one and one-half billion bushels or around a third of the World's production. High prices during World War I were largely responsible. In 1919 more oats were grown in the north central oat belt and in the southern half of the Great Plains area, especially in Central Texas, but fewer in the West and Southeast.

Oat production remained about stationary during the next two decades. Some expansion occurred in Idaho, Montana and other intermountain States, and in the western Dakotas, Nebraska, Oklahoma and Texas, but oat culture decreased in New England, New York and other eastern States.

In the decade ending with 1949 oat production reached its peak with the crop approaching or exceeding one and one-half billion bushels in four of the ten years. The distribution of improved disease-resistant varieties increased both acre yield and quality, thus markedly raising the economic status of the crop. For the first time a crop grown of necessity was transformed into one of choice. Production of oats should continue to contribute greatly to the National agricultural economy of the United States.

Varieties Grown in the United States

There are relatively few distinct and widely divergent morphological types of oats, although there are many named strains of the several more or less distinct botanical varieties grown in the United States. Likewise, there are many varieties of oats which, because of productiveness, stiff straw, superior grain quality, suitability for combining, desirability for feed and processing, are of much agricultural importance, but they are difficult to classify.

Fortunately the oat varietal situation in the United States has greatly improved in recent years. Varietal registration, seed certification and generally more productive varieties have served to make the farmer much more varietal conscious, and, as a result, the number of mixed, nondescript and otherwise unsatisfactory varieties grown on farms has been greatly reduced. Furthermore, in most sections of the United States farmers now demand varieties with protective resistance to the major diseases, especially the rusts. Such resistance is essential for successful production of the crop in many areas. No feasible means of protection against losses from rust other than the growing of resistant varieties has been found.

Resistance to the oat smuts also is very desirable, but this disease can be easily and cheaply controlled by seed treatment with fungicides. Therefore, smut-resistant varieties are not so necessary as rust-resistant varieties. In the more northern oat-producing areas of the country, certified-seed inspectors report that smutted panicles are difficult to find in oat fields. In fact, it is now necessary for pathologists and breeders to grow special plots to produce smut spores for experimental use. Hence the great reduction in losses from oat smuts through breeding resistant varieties and by seed treatment has been an important accomplishment in crop improvement.

In the great North Central oat-producing region of the United States there were two great shifts in the type of varieties grown during the past decade. Similar changes occurred in other regions. These shifts were due primarily to the increasing losses caused by crown rust and also to the occurrence of a new disease hitherto not known to attack oats.

Prior to 1940, varieties with little or no resistance to crown rust were grown, but a few with protective resistance to stem rust had become popular, such as Anthony, developed by the Minnesota station. This oat was first distributed to farmers in 1929. The increasing prevalence of crown rust, which followed the control of stem rust, made poor oat years the rule instead of the exception, especially in the Corn Belt. The future of the oat crop seemed to be jeopardized. Naturally there was a growing demand for varieties that also were resistant to crown rust.

During the thirties the important stem-rust-resistant varieties grown mainly in the Corn Belt were Richland (Iowa No.

105), Iogold, Rainbow and Anthony. The old White Tartar (White Russian), a low-yielding side oat, also was grown to some extent in the Red River Valley region of Minnesota and North Dakota. Some of the other popular varieties without special disease resistance that were grown in certain areas in the northern half of the United States were Albion (Iowa No. 103), Gopher, Iowar, Nebraska No. 21, Maine No. 340, State Pride, Cornellian, Ithacan, Keystone, Wayne, Wolverine, Forward, Cartier, Minota, Banner, Silvermine, Swedish Select, Golden Rain, Wisconsin Wonder, Abundance and Victory.

The smut-resistant Markton oat, first distributed in the Pacific Northwest States in the early twenties, was unadapted to the Corn Belt and northeastern States because of its high susceptibility to rusts. Fulton, a smut-resistant oat that originated from a cross made in 1926 on Markton, was first distributed to farmers of Kansas in 1929.

By crossing Markton on Victory, Idamine and Swedish Select in 1923, a group of midseason white oat varieties with the smut resistance of Markton were developed and distributed in the Rocky, Intermountain and Pacific Northwest regions. These new varieties included Bannock, Uton, Bridger, Mission, Marida and Shasta. They, like Markton, were too susceptible to the rusts for growing in the great Upper Mississippi Valley oat region. The only exception was the productive, related smut-resistant Huron that was distributed and grown extensively in Michigan. Nevertheless, it remained for the advent of varieties resistant to both crown and stem rust and to smut to establish a high-water mark in oat improvement in the United States.

Varieties with Protective Resistance to Crown and Stem Rusts. Marion, resistant to smut, stem rust and some races of crown rust, was developed from a Markton-Rainbow cross made in 1928, and first distributed in Iowa in 1940. It has persisted because of its resistance to Victoria blight discussed below and is still grown rather extensively in eastern Nebraska, less extensively in Iowa, Michigan and the Dakotas.

After the introduction of the Victoria variety from Argentina in 1927 and discovery of its resistance to crown rust and the oat smuts in 1929, crosses were made on Richland (Iowa No. 105) and other oats, from which new varieties were evolved with a combination of resistance to crown rust, stem rust and smut, and also with better agronomic characteristics. Varieties with such a satisfactory combination of resistance to the major diseases had not been available previously.

The Victoria-Richland cross made in 1930 gave rise to temporarily widely grown varieties—Tama, Vicland, Boone, Cedar, Control, Vikota. These varieties, distributed in the early forties, had replaced nearly all the older varieties in the North Central oat region by 1945. Along with other Victoria-derived varieties, such as Osage and Neosho, they made oats a much more certain and a much better crop, especially in the North Central States, in which region four-fifths of the national crop is produced. Resistance to rusts and smuts was combined with stiffer straw, higher yield and better grain quality.

Victoria Oats Susceptible to a New Disease. A new disease known as Helminthosporium or Victoria blight (*H. victoriae* Meehan and Murphy) was discovered at the Iowa State College in 1944. The *H. victoriae* organism had been observed on timothy and some other grasses in the United States, but not previously on oats. The blight began to show up in widely distributed fields of Boone, Tama and Vicland in 1945, and became widespread and destructive by 1946. Thus a valuable new and productive group of varieties was

nearly wiped out, and a demand for resistant varieties to replace them became urgent. Only the Victoria and Victoria-related strains proved to be highly susceptible to this disease, and this high susceptibility is strongly linked genetically with the type of crown rust resistance found in Victoria and Victoria derivatives. Although much work has been done, no one has yet succeeded in breaking this linkage so that the excellent type of crown rust resistance in Victoria can be salvaged for future oat breeding. Victoria blight is one of the most destructive diseases ever to attack oats in the United States and Canada. Since it attacks only Victoria or related varieties, the disease will disappear with replacement of these varieties by resistant germ plasm.

Varieties from Bond Crosses. Fortunately American oat breeders had not been " asleep at the switch " when Victoria blight became so destructive. A new group of resistant selections from Bond crosses were ready for naming and distribution. Bond was introduced from Australia by the U. S. Department of Agriculture in 1929 and was found to have a better type of resistance to crown rust than that possessed by Victoria, in addition to having a very stiff straw and plump thin-hulled grains. In fact, Bond is the stiffest-strawed variety ever introduced into the United States. Bond, a red to grayish-red oat belonging to the group *Avena byzantina,* had been crossed on Iowa No. D69, Iowa No. D67, Anthony, Rainbow and other varieties in the early thirties. From these many new varieties were evolved that were grown from 1946 to 1951 with remarkable success.

The one most important and widely grown Bond-derived variety has been Clinton which originated from the cross, Iowa No. D69 × Bond, at the Iowa Agricultural Experiment Station in cooperative experiments with the U. S. Department of Agriculture. It was grown on approximately 75 percent of the oat acreage of the United States in 1950. Other Bond-derived varieties, which have been grown on smaller acreages, include Mohawk and Advance in New York, Bonham and Kent in Michigan, Benton in Indiana, Bonda, Mindo, Andrew and Zephyr in Minnesota, Colo and Shelby in Iowa, Nemaha in Nebraska, and Cherokee in Kansas. The productiveness, earliness, stiff straw and high-test weight of these varieties made them great favorites among farmers. Likewise their excellent grain quality has made them very desirable for feeding and processing.

New Races of Rust Threaten Bond-Related Varieties. Since the distribution of the above Bond-related varieties, previously known but hitherto relatively unimportant races of both crown and stem rust have become more prevalent, infecting these new varieties and causing losses in yield and quality. Scattering pustules of crown rust races 45, 57 and similar races (strains) were found in fields of Clinton, Benton and similarly derived oats in the late nineteen forties but with no appreciable reduction in yield. However, by 1950 these races, especially race 45, had built up and became much more prevalent under favorable conditions for rust. They caused some losses, especially to Clinton, because of its wide distribution and intensive culture in the North Central and northeastern oat regions.

The virulent and comparatively new race 7 of stem rust also appeared in epiphytotic proportions in 1950, and it injured oats rather severely in the west North Central States, especially in the Dakotas. Owing to weather and other conditions unfavorable for rust development in 1951, neither race 45 of crown rust nor race 7 of stem rust developed to any appreciable extent.

However, with the early knowledge

that the Bond derivatives were susceptible to race 45 and similar races of crown rust, steps were taken to fortify the crop by breeding for resistance. Varieties such as Santa Fe, Landhafer and Trispernia with resistance to race 45 and 57 were available as foundation stocks. Santa Fe was introduced from South America in 1945, Landhafer from Germany in 1938 and Trispernia from Canada in 1941 which previously had been brought to that country from a European source. The belief prevails, however, that both Landhafer and Trispernia also probably had their origin in South America.

Many new crosses involving these varieties were made during the early forties, from which numerous new experimental strains with desirable agronomic characters carrying resistance to race 45 and similar races were selected and developed. As an example, in breeding experiments conducted at the Iowa Agricultural Experiment Station in cooperation with the United States Department of Agriculture, new resistant strains similar to Clinton and Benton in many plant and grain characters have become available. The Clinton oat is still near the peak of its popularity. On the other hand, if the incidence and destructiveness of crown rust race 45 and similar races continue to increase on Clinton and related oats, new strains are available for rapid multiplication and distribution to replace them.

Steps also are being taken to fortify all Bond-related oats against race 7 of stem rust. Satisfactory resistance is available in Canuck and similar related Hajira-Joanette strains developed in Canada during the late twenties. Already various crosses have been made on these varieties, resulting in numerous new experimental strains with resistance to race 7 of stem rust in combination with desirable agronomic characters that can be increased and distributed if infection by this race becomes widely prevalent and destructive.

As a consequence, varieties with superior agronomic characters and carrying a combination of satisfactory resistance to all known races of crown and stem rust should become available within a few years. If the appearance of new races could subside for a while, the oat breeders would be able to give more time to basic research on the diseases and genetics of oats.

Winter Oat Varieties. Marked progress also has been made in breeding varieties of fall-sown oats for the South. A number of hardy crown-rust resistant varieties have been developed and distributed for both grain and grazing. The development of new winter varieties parallels the breeding of improved disease-resistant spring varieties in that both Victoria and Bond in turn were used as sources of resistance to crown rust.

By crossing Fulghum, Lee and Red Rustproof on Victoria, new and better varieties, such as DeSoto, Fultex, Letoria, Stanton, Traveler, Ranger and Rustler, and numerous other crown rust-resistant productions were bred and distributed. However, these in the lower South succumbed to Victoria blight in 1947 and 1948, and were largely replaced by resistant Bond-derived oats, including Florida No. 167, Coker No. 45–67 and Camellia. These varieties in turn under the very favorable conditions for the development of fungus diseases in the South fell victims of crown rust race 45 and have been for the most part replaced by varieties with some degree of resistance or tolerance to race 45, for example, Victorgrain No. 48–93, Southland and Mustang.

Owing to the heavy losses caused by Victoria blight and race 45 of crown rust, named strains of the old Red Rustproof oat of the South, such as Appler, Red Rustproof No. 14, Delta Red No.

88, Nortex, New Nortex and Ferguson No. 922, are again being more extensively grown, especially in the old Cotton Belt area. This type of oats has persisted for 75 years in this area because of its great vigor and some tolerance to rust and other diseases not found in other types. Its well known disadvantages are late maturity, numerous awns and generally low test weight. However, it is believed that eventually new disease-resistant red oat varieties will be developed that will replace these old Red Rust-proof type oats.

Further improvement of oats for the South by breeding for better disease resistance, greater winter resistance and superior agronomic characteristics still offers a fertile field for the oat breeder. As is also true of spring oats, much more fundamental research on the origin, life history, mode of inheritance of disease and plant characters must be undertaken with winter oats to provide data and information on which to base a sound breeding project. Results to date demonstrate rather conclusively that a successful oat culture can be developed even for the deep South if better and more lasting resistance to the rusts and other diseases can be found and transmitted to the best agronomic types. The search for a wider diversity of germ plasm carrying resistance to the rusts is being intensified to stock-pile resistance that may be needed as new physiologic races (strains) of the oat rusts appear.

Varieties Grown in Other Countries

Recent information on varieties of oats grown in most foreign countries is rather limited, owing to the interruption of much crop improvement work incident to World War II. Stanton[9] has summarized the breeding and distribution of varieties in many countries prior to 1936. It may be said that many of these varieties are still standard in these countries as a result of the absence of diseases and a much slower turn-over of agricultural varieties than in the United States.

[9] Previously cited on page 48.

Western Hemisphere

Canada follows the United States as the only other important oat-producing country of the Western Hemisphere. Argentina ranks next with a production of about one-seventh that of Canada. Uruguay, Chile and other countries produce some oats. Brief statements on the varieties cultivated in these countries are given below:

Canada. The oat varieties in Canada are similar to those grown in the more northern oat sections of the United States. They are mostly midseason to late, rather tall, white-seeded varieties. The cooler climate of Canada is very favorable to these later types of common oats, and they produce high yields of grain of excellent quality. Many of the newer productions are resistant to all races of stem rust.

Popular varieties grown in Canada today include several of the more recently developed and distributed sorts, namely, Abegweit, Ajax, Beaver, Exeter, Fortune, Roxton and Vanguard, some of which are resistant to stem rust. Other varieties, a few of which have been grown for a long time and have little or no rust resistance, are Alaska, Abundance, Banner, Cartier, Eagle, Erban, Gopher, Larain, Legacy, Mabel and Victory. The late black-seeded oat, Old Island Black, is still grown on a few farms in the maritime province of Prince Edward Island.

Argentina, Uruguay, Chile. The varieties grown in these countries consist primarily of named strains of the Red Algerian oat (*Avena byzantina*) or closely related types, such as Argentina, LaPrevision No. 13, LaEstanzuela No. Bid., Klein Victoria and Klein Mar. Red

Algerian and Argentina are morphologically similar to the Red Rustproof oat of the southern United States. Common or white oats belonging to the group, *A. sativa,* are poorly adapted in these countries and thus but little grown.

Mexico. Most of the oats grown in Mexico represent somewhat nondescript, very early to early short-strawed types. A collection of about 60 varieties, secured by B. B. Bayles from the Agricultural Department at Mexico City, were of a type intermediate between red and common oats. It would appear that these oats are probably related to the old Burt variety which was grown rather extensively in the southern part of the Corn Belt of the United States several decades ago. These early, small-seeded, slender-strawed, disease-susceptible Mexican varieties or strains proved to be of no promise when tested in the southern United States.

Eastern Hemisphere

The Eastern Hemisphere includes the important oat-producing countries, the British Isles, Russia, France and Germany. Oats are of some importance also in many smaller countries of Europe and Asia, although relatively only small areas are devoted to the crop. For a partial list of the varieties of oats grown in the British Isles, France, the Scandinavian countries, Germany, Asia, Africa and Australia, see Footnote 6.

The cool moist climate of northern Europe, especially that of the British Isles and the Scandinavian countries, is very favorable to the growth of the oat plant. Oats also are well adapted to many parts of Russia, although the climate is not so favorable as in the countries to the east. In all these countries diseases are not very common and do not constitute much of a limiting factor in oat production. In the British Isles and Scandinavian countries destructive diseases, such as crown and stem rust, so common in the New World, are little known. The low, uniform, maximum summer temperatures are not conducive to the development and spread of these diseases.

The rather cool climate of France, especially northern France, and of Germany likewise is favorable to oat production, and the varieties of common oats (*Avena sativa*) are grown almost exclusively. Oat rusts occur in these countries but have not been so common or destructive as in the United States and Canada. In the countries bordering on the Mediterranean the climate is much warmer, and red oats similar to those cultivated in our southern States and in Argentina constitute the important varieties of the region. Red oat varieties also predominate in South Africa and Australia. In India very short small-strawed varieties, morphologically similar to some of the American types intermediate between common and red oats, are grown. However, the warm climate of India is generally very unfavorable to oats, and consequently the crop is of only minor importance. Some of the Indian varieties have been tried in north Florida and other sections of southern United States but with poor results.

Growing the Crop

Oats respond well to proper cultural methods. In the United States, especially in the Corn Belt where oats most frequently follow corn, the seed bed is usually prepared simply by disking before seeding. This is good practice, and in the absence of heavy crop residues plowing seldom is necessary.

Drilling the seed is usually preferable, although the end-gate seeder for sowing oats is still extensively used, as less work is required and frequently more timely seeding is obtained. Nevertheless, drilling is a more accurate method of sowing which requires less seed, insures a more

uniform distribution and more complete coverage of all seed. Drilling also places the seed at a uniform depth in the soil.

As a rule it is more profitable to apply commercial fertilizers to other crops in the rotation than to oats. Under certain conditions, however, fertilizers may be applied directly to the crop with good results. In some sections a greater acre return per unit of fertilizer can be obtained from oats than from wheat or corn.

Usually farm manure is not applied directly to oats because of the danger of producing excessive straw growth and consequent lodging. As a rule, where soil amendments are needed, complete fertilizers of the formulae 5–10–5, 6–12–6 or similar combinations are applied. In any region where inclusion of soil-building legumes in the rotation supplements the nitrogen in the soil, application of 200 to 250 pounds of superphosphate at time of seeding is an excellent fertilizer treatment for oats. In cold wet springs light applications of nitrate of soda, ammonium nitrate or other nitrogen fertilizers will be beneficial to the crop until the soil warms up sufficiently to bring about nitrification. Much of the so-called " red leaf " trouble or mal-nutrition manifestations in oats in the spring is due to lack of readily available nitrogen at a critical period in the growth of the plant. Hence nitrogen alone on the better soils or a complete fertilizer on somewhat less fertile soils applied at time of seeding should become a more general practice in the culture of oats in many sections.

Application at time of seeding of from 200 to 300 pounds of a complete fertilizer containing equal proportions of nitrogen, phosphorus and potash, that is, of a 12–12–12 or similar formula, is giving excellent results in some sections.

Common rates of seeding oats range from eight to ten pecks to the acre. Under dryland farming the rate is usually reduced to six pecks, and under irrigation it is frequently increased to 12 pecks.

Seeding as early as the land can be prepared in the spring usually is advisable under nearly all conditions. Deferred sowing after the optimum date may decrease yield as much as three bushels per day for each day of delay. Winter oats should be sown three to four weeks before the first killing frost for the section.

Seed treatments with fungicides for control of oat smuts and other seed-born diseases is a common practice among good farmers.

Harvesting

In the United States the oat harvest extends over a period of about four months. Harvesting begins in the South with winter oats in early May. The bulk of the spring-sown oats is usually harvested in July and August, depending on the latitude. However, following delayed seeding resulting from cold wet spring weather, harvesting may be as late as September 1 or even later in the more northern oat areas.

Methods and machines for harvesting oats and other small grains have been greatly improved in both capacity and efficiency in recent decades. Within a period of 75 years the method of harvesting oats has advanced from the old-fashioned cradle to the modern 14-foot self-propelled combine which harvests and threshes at one operation. Thus in the space of a life-time the rate of harvesting oats has increased from an acre or two a day per man to 30 or more acres a day per man. In many sections the cradle is not known to the present generation of farmers. It was followed by the reaper which cut the grain and delivered it in short gavels which could be easily bound into bundles by straw bands made by a characteristic turn of the wrists. This was followed by the self-binder, one of the truly great inven-

tions, which cut and bound the grain into bundles by the use of binder twine made from Manila hemp or sisal fiber and dropped them into windrows for shocking. The development of the self-binder, as indicated above, marked the beginning of a new epoch in the agriculture of the United States. Few agricultural inventions have contributed so much to the advancement of agriculture, the national economy and the "American way of life" as has the grain binder.

Headers which removed just the panicles or heads from the straw also came into use, especially in the semi-arid regions. The barges of headed grain were hauled to a convenient location in the field and then stacked. Later in the season these ricks or stacks of headed grain were threshed with a modern separator in the same manner as bundle grain would be threshed from the stack or shock.

The greatest perfection in harvesting methods was reached with the development of the modern self-propelled combine which cuts and threshes the grain and delivers the bulk grain to a tank truck ready for hauling it to the granary or elevator.

The binder, however, has not been completely replaced by the combine, for it is still preferred in many areas where small acreages of oats are grown. Binders also are still used in some sections because the straw is saved for roughage and litter, and farmers do not have to take chances of letting the oats stand in the field to become sufficiently dry for combining. Binders also are frequently preferred on irrigated farms, owing to small fields and the obstruction offered

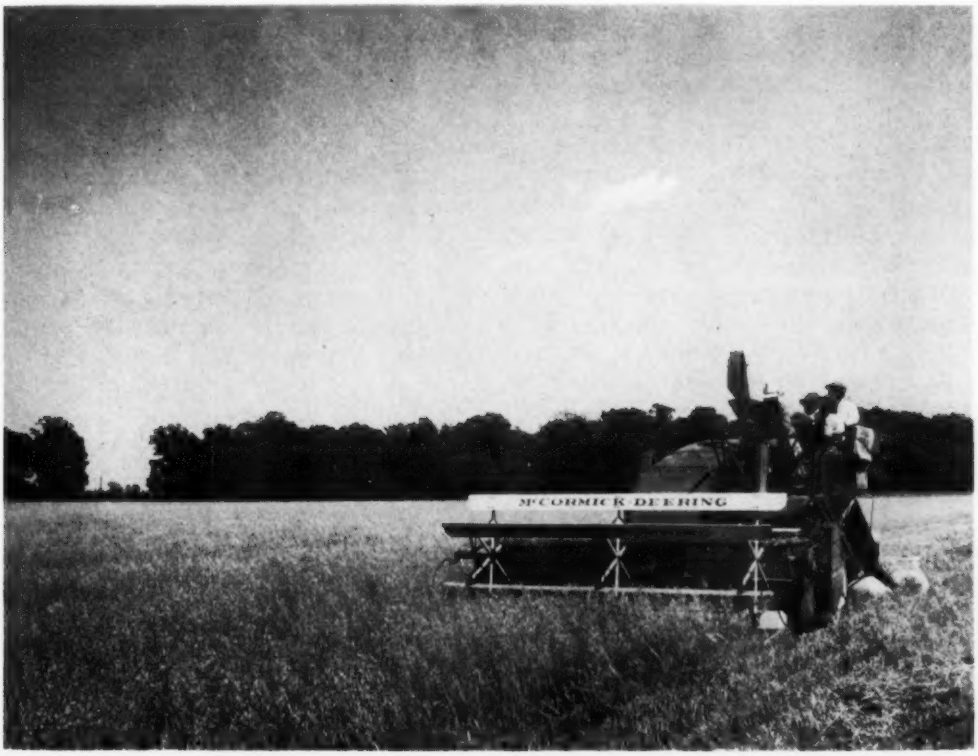

FIG. 3. Harvesting oats with a modern self-propelled combine in South Carolina.

to the convenient operation of the combine by irrigation ditches and levees.

Storage

As noted previously, more than 85 percent of the oats produced in the United States is consumed by livestock on the farms or elsewhere in the counties where produced. Safe storage of oats on the farm is very essential. However, in the cash oat-producing area of northern and northwestern Iowa, much of the commercial oats is hauled to local elevators or warehouses immediately after harvesting.

In storing oats either in farm granaries or in elevators it is important to have the grain dry enough, not exceeding 14 percent moisture for safe storage when put into the bin. If the oats contain excessive moisture when stored they may become musty or heat damaged, thus greatly reducing their feeding and market value. Oats stored with less than 14 percent moisture with full protection from dampness from without will remain sweet and in good condition for several years if storage for so long a period becomes necessary [10].

The grain storage bin or granary should be well built and strong enough to resist the pressure of the grain and also be rodent proof. Oats have the advantage that, owing to their lighter bushel weight, danger of springing leaks from pressure within the granaries is much less than the case of wheat or rye. Modern farm granaries are equipped with elevating machinery, thus saving hand labor, and are so constructed that the oats can be removed conveniently and economically.

[10] For general information on oat and other grain production and storage, see Collier, G. A. Grain production and marketing. U. S. Dept. Agr. (Production and Marketing Administration), Misc. Pub. No. 692. 78 pp. illus. Oct. 1949.

Utilization

The great bulk of the oat crop the world over is utilized as feed. Oats have only limited industrial uses.

Feed

In the United States oats constitute a leading concentrate in rations for horses, cattle, sheep, hogs and poultry. The proportion fed in other countries is probably even higher, as in no other country are rolled oats consumed to the extent they are in the United States, except possibly in the United Kingdom, in which Scotland is a heavy consumer of oat porridge made from oatmeal. Incidentally it should be mentioned that oatmeal or rolled oats is one of the cheapest yet one of the most wholesome, palatable and well-balanced foods available for children and adults. In case of food shortage or famine much greater quantities of rolled oats could be made available at relatively low cost for feeding the population [11].

It has long been known that oats constitute the one best feed or concentrate for horses. Special high quality grades, called "race horse" oats, are sold to horsemen. The feeding of high-test weight oats to race horses is so highly regarded that turfmen are willing to pay a considerable premium above the market price for extra quality oats. They believe that oats give race horses a stamina and energy not obtained from feeding other grains.

After the advent of the automobile and farm tractor, some economists predicted that with a rapidly decreasing horse population the big oat crop produced in the United States could no longer be utilized and that oats would become a very unprofitable and surplus crop. This did not materialize because

[11] Stanton, T. R. More food value for money obtainable in rolled oats. Chicago Jour. Commerce **28**(147); pp. 10a and 14a, April 5, 1948.

oats were widely adopted as feed for dairy cattle and poultry, and the surplus was absorbed. As a consequence, no radical change in the national economy of oats in the United States followed the shift from the " horse and buggy days " to the present mechanized agricultural age. In fact, today considerably more oats are fed to dairy cattle and poultry than were fed to horses at the height of the horse population around 1918. More and more oats are being fed to turkeys not only because of the constant and rapid increase in the turkey population but because oats continue to make up a greater proportion of the ration each succeeding year. Some oats are utilized in the form of groats, dehulled or hulled oats, as feed for baby chicks, squabs and other young fowls. A small quantity also is used for making poisoned bait for destroying grasshoppers and certain troublesome rodents.

Incidentally it should be mentioned that a very small quantity of high quality oats, usually of the Victory variety, are used for growth studies on the bending of the oat coleoptile by light or other external stimuli. Oats have been used almost exclusively for this type of research, on which subject hundreds of papers have been published. Thus oats occupy a peculiar place in relation to the other small grains as being an outstanding biological tool of plant physiologists interested primarily in tropism.

FIG. 4. A commercial oat mill in Cedar Rapids, Iowa.

Processing

Oatmeal. About 50 million bushels (800,000 tons) of oats are used in the

United States each year for manufacturing oatmeal, or rolled oats. This is about four percent of the national oat crop. Other oat products for breakfast food and some new uses for products from this grain have been developed. These and other products made from oats have been recently discussed [12].

The first step in the milling of oatmeal is to clean, dry and toast the oats to make the hulls dry and brittle so that they can be more easily removed by the hulling stones. Toasting also develops a more tasty flavor in the groat, which is carried to the final product. The next step is to separate the groats, or oat kernels proper, into grades on the basis of length and diameter, followed by steaming, cutting and rolling the groats into flakes and then packaging. About 13.5 bushels, or 432 pounds, of medium good to good oats are required to produce a barrel, or 180 pounds, of high-quality rolled oats. The milling extraction varies with the quality of the grain milled but ranges from 35 to 65 percent. The heavier and somewhat plumper commercial oats give the highest extraction of rolled oats. During recent years the thin-hulled high-test weight oats produced by the new disease-resistant varieties, such as Cherokee, Clinton and Bonda, have given the highest milling extraction of the best quality rolled oats ever processed in the United States.

Oat Flour. Oat flour, a by-product of rolled oats manufacture, contains no gluten. Hence it cannot be used for baking bread except when mixed with about four parts of wheat flour to one of oat flour. Several relatively new uses for oat flour have been developed. Oat flour, because of an antioxidant which it contains is used to preserve quality by delaying the development of rancidity in fat-containing foods. For this purpose it is infused with lard, margarine or peanut butter, is dusted on potato chips and salted nuts, and is used to coat paper containers of food stuffs such as bacon and coffee.

Avenex, a special grade of oat flour, is utilized as a food preservative, particularly for milk, ice cream, fish, fish fillets and candies.

Oat Hulls. The rolled oats mills produce about 210,000 tons of hulls from the 800,000 tons of oats milled each year. Each 235 bushels of milled oats, testing 32 pounds to the bushel, produces about a ton of hulls. Oat hulls, fed either as ground hulls in the mash or in the form of whole oats in poultry rations, serve mainly to protect against slipped tendons, canibalism and feather picking in chickens. Thus some of the most valuable ingredients of whole oats as feed for poultry is contained in the hull.

Furfural. Furfural is the most valuable product made from oat hulls, and about 200 pounds of it are obtained from a ton of the hulls. Furfural can be made also from other farm wastes and products, e.g., cornstalks, corncobs, bagasse and rice hulls, but few of these products give as high yields of furfural as do oat hulls. Owing to the great demand for furfural, factories have been recently established to make this product from corn cobs.

Furfural is a major solvent or chemical intermediate in the processing and refining of mineral and vegetable oils. Other important uses for it are in the purification of wood rosin and the production of synthetic resins, such as bakelite.

Use of furfural as a raw material for the making of adiponitrile, a nylon intermediate, was developed in the middle forties. Thus through an exacting synthetic and complicated process, nylon is evolved from oat hulls, and the demand for furfural in the making of nylon has increased many fold in recent years. The tremendous increase and use of

[12] Stanton, T. R. New products from an old crop. U. S. Dept. Agr., 1950–1951 Yearbook: 341–344.

nylon for the manufacture of ladies hose and other articles of clothing has been a processing and merchandising achievement of the first magnitude, resulting from the creative and technical genius of "American Men of Science".

Pharmaceutical products also have been made from oat hulls. These have been synthesized from the furan resins mentioned above, and include Furmethide and furacin, the latter an antiseptic and possible supplement for penicillin or streptomycin. Furan compounds have a wide range of possible medical applications.

The Future of Oats

In previous paragraphs it has been made clear that the economic status of the oat crop in the United States has been greatly improved during the past decade mainly through the breeding and distribution of disease-resistant, more productive, stiffer-strawed and higher quality varieties. There is still much need for further improvement through breeding for disease resistance, greater winter-hardiness in fall-sown oats, superior pasture characteristics and a better understanding of the relationship of plant growth to environment. There is not as yet any perfect oat variety, and consequently intensive breeding must be continued. The apparent constant threat of new physiologic races of the oat rusts must be met through more intensive research in the use of a greater diversity of germ plasm and improved breeding techniques if oat production is to be maintained by making resistant varieties available to the farmer. The needs in the various fields of research for further oat improvement in the United States have been discussed [13]. It is evident that perfection in oat improvement is yet only an ideal to work towards and to be attained by meeting the hazards of disease and other unfavorable factors as they arise.

The development of better methods of breeding oats through the perfecting of cytological and cytogenetic research techniques for producing chromosal aberrations by application of X-rays, radium, heat, cold and various chemical compounds must not be neglected. In this field only the surface has been scratched.

There also are other phases of oat improvement needing attention, such as the development of feasible and practicable methods of controlling the rusts by application of new fungicides. Spraying oat plants with new compounds, such as urea to step up yield, or with other chemicals to reduce weed damage, is a future possibility.

Increasing Oat Production by Greater Use of Fertilizers

In the future oat production can be greatly increased by a much more general and liberal use of commercial mineral fertilizers. Much heavier applications than is now the common practice would result also in decidedly higher acre yields and improved grain quality. Conservative estimates indicate that the annual average acre yield of oats in the United States could be doubled by greater and more rational use of commercial fertilizers if and when a much greater national production should become necessary. This, of course, would require a much greater production of commercial fertilizers and a corresponding increase in the processing industry. In some European countries, France and Germany, for instance, where an exceedingly intensive type of agriculture is practiced in which heavy applications of fertilizers, including organics insofar as they are available, are made, the acre yields on the average are more than double those of the United States and other extensive oat-producing countries.

[13] Stanton, T. R. Oat improvement for the next quarter century (Better oats for tomorrow). U. S. Dept. Agr., Bur. Plant Indus., Soils and Agr. Eng., 23 pp. 1946. [Processed].

In the field of agricultural research much more experimental work is needed in the use of fertilizers for augmenting the yield and quality of oats. For example little is known concerning the value of mineral fertilizers for preventing winter-killing in fall-sown oats. Likewise the increasing occurrence of various nutritional deficiency diseases in oats expressed by " red leaf ", foot rots and other unhealthy plant symptoms, is becoming of increasing concern to agronomists, plant pathologists and physiologists. It is apparent that lack of nitrogen available to young oat plants in the spring until soil temperatures become sufficiently high to bring about soil nitrification has become a deterrent to oat production in many areas. There is little doubt that this condition is mainly, or at least in part, responsible for much of the increase in the so-called " red leaf " troubles that have been more apparent in recent years. Thus lack of nitrogen as well as of other major or minor elements at a critical growth period in the life of the oat plant appears to be a major cause of the various difficult-to-understand malnutritional manifestations in oats, especially in cold wet springs.

More Diversified and Industrial Uses of Oats Needed

Aside from those already discussed, many new industrial uses for oats must be found. This lack of spectacular industrial phases has been the one factor that has relegated oats into the category of being considered as just a " feed crop " by many economists and agronomists. If new uses cannot be developed, oats will remain of relatively less industrial importance than either wheat or barley.

Oats, because of their natural high nutritional value, should be subjected to much more explorative research on the part of nutritionists and processors for possible development of new and better food products. In cereal chemistry the characteristics of the starches and amino acids in oats is still for the most part an unexplored field. Why are only high quality oats demanded as feed for race horses as the sole concentrate in the ration? What is the active principle appearing to increase vigor or stamina in race horses that must exert every ounce of their energy to win on the tracks? These are just a few of the questions that arise regarding the value of oats for food and feed. Further extensive research along these lines might pay big dividends in an expanded utilization of the crop industrially.

Utilization Abstract

Citrus By-Products of Florida. In the 1949–1950 season, 48 million boxes of oranges and grapefruit, a little more than half of the total crop in Florida, were processed, principally into juice concentrate, leaving two million tons of refuse to be disposed of by the citrus by-product industry. Dried citrus pulp, molasses and citrus peel oil are the three primary by-products; citrus seed oil, alcohol, pectin, bland syrup and feed yeast are produced to a smaller degree.

The dried pulp and molasses are used as livestock feed, and stripper oil, obtained as a by-product in the manufacture of molasses, has found use in the manufacture of a synthetic spearmint oil flavor, in the paint and varnish industry, as an ingredient of clear plastics, as a base for soap perfumes and as a penetrating oil. Cold pressed and distilled citrus peel oils find utilization in perfume and toilet goods, beverages, extracts, baked goods, canning, condiments, confectionery, ice cream, preserves, pharmaceuticals, alcoholic beverages and soap. (R. Hendrickson and J. W. Kesterson, *Univ. Fla. Agr. Exp. Sta., Bull. 487. 1951*).

The Development of Domestic Castor Bean Production[1]

Shatter resistance, earliness, high yield and plant form best adapted to mechanical harvesting have been the principal and already partly achieved objectives in breeding castor beans, which, along with improvements in harvesting and hulling machinery, increase the prospects for greater domestic production of this crop.

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The castor bean now appears to be accepted as a permanent farm crop in the United States. Within the period 1947 to 1951, domestic acreage increased from zero to some 84,000 acres, with bean production reaching about 40,000,000 pounds annually. Production goals for 1952 were about 200,000 acres and over 100,000,000 pounds of beans [2].

Castor beans have been processed domestically for oil since the early 1800's. The volume processed has increased enormously, particularly in recent years, because of the scores of industrial uses for castor oil and its derivatives. During this long period of increasing consumption of castor beans, domestic culture of the plant has been started no less than three times, but each time it failed to continue.

The rapid recent increase in domestic acreage and the apparent permanence of present production give cause for an analysis of the factors which have made those two features possible.

Early Production

In the 1800's there was appreciable acreage in that part of the United States extending east and south from central Kansas. Harvesting and hulling of that production was entirely by hand, just as the crop is handled today in foreign countries. Without hulling machines, the varieties necessarily were such that they shattered their individual beans naturally at maturity. This characteristic required frequent hand-harvesting of the fields. The harvested spikes were exposed to the sun to permit shattering, after which the chaff was winnowed from the beans to produce the marketable product. The high labor requirement of this method caused domestic production to give way completely to imports after the early 1900's.

Two later emergencies, World Wars I and II, created the need for domestic production of beans, and during both periods the Federal Government undertook programs to have the crop grown.

[1] This paper has been reviewed by Mr. Milo Arms, Mr. L. G. Goar, Mr. Albert Hoffman, Dr. P. F. Knowles, Mr. Harry Smith, Dr. D. L. Van Horn and Mr. R. O. Weibel.

[2] The impetus for this expansion lies in the facts that about 350,000,000 pounds of castor beans or about 125,000,000 pounds of castor oil are annually needed for industrial purposes in the United States, 95% of which has for years been imported as seed or expressed oil, principally from Brazil and Mexico. For further information on the effort to free American industry from dependence on foreign sources, and for data on the early industry in the United States as well as other aspects of castor bean utilization, see ECONOMIC BOTANY 1: 116. 1947; 2: 273. 1948; 6: 175. 1952. [Editor].

The first of these two efforts resulted in very few beans being produced, largely because of the lack of both adapted varieties and agronomic know-how. The second venture was somewhat more successful because seed stocks of quite shatter-resistant varieties were selected from American strains, areas were first tested for production, and workable hulling machinery was available. A maximum of some 6,000 acres was grown in 1943. There was no machinery for harvesting, however, and the acreage dropped to zero with the withdrawal of the Government's purchase program at the end of the 1943 season.

It was apparent from the experiences just related that castor beans could not become established as a permanent crop in American agriculture until: (*a*) varieties were developed with characteristics of desirable plant form, adaptation to specific localities, shatter-resistance which would permit a single harvest, and high yield; (*b*) machines were developed for mechanical harvesting; (*c*) hullers were perfected; (*d*) handling equipment and methods were devised; (*e*) grading procedures and marketing methods were developed; (*f*) growers were provided with technical advice on cultural, harvesting, hulling and handling methods; and (*g*) growers were assured a market for their crop.

The current domestic commercial production of castor beans is felt to be permanent and is the result of both (*a*) coordinated research programs on agronomic, engineering and marketing problems, and (*b*) a production program involving seed increase, publicity, contracting and technical service to growers.

Agronomic Research

Adaptation. Whereas technical research programs on castor beans did not begin until the 1940's, each of the three production attempts before 1943 gave certain clues to the best adaptation of the castor plant. It was no doubt from trial and error that Kansas and Oklahoma became the largest producing center in the late 1800's. During the First World War the production program covered much of the southern part of the United States, but the lack of adaptation of the seed stocks to any part of the United States made impossible the critical evaluation of the different agricultural areas.

During the Second World War, in addition to the scattered commercial acreages, the agricultural research agencies of the Federal Government and several States made experimental plantings throughout the southeastern quarter of the United States and in southern California, Arizona and New Mexico. The conclusions then were that the crop was best suited, agronomically and economically, to an oval-shaped area extending from the Panhandle of Texas on the Southwest to the southern tip of Ohio on the Northeast. This area was delineated on the West by too little rainfall, on the North by too few frost-free days, and on the South and East by a disease hazard resulting from excessive rainfall and humidity.

As one part of its extensive effort to get an assured large domestic supply of castor beans, which would be difficult to obtain in non-irrigated areas, The Baker Castor Oil Company in 1947 undertook a program of variety development which has produced types (see below) that make the production of castor beans on irrigated lands in California, Arizona and New Mexico economically practical. Thus the area of agronomic and economic adaptation in the United States has been extended westward to include the dry irrigated valleys of at least these three southern States. At the same time the eastern boundary of best adaptation is considered by many to have now moved westward to a line passing through parts of Missouri and Arkansas.

Cultural Methods. To some extent the failure of production efforts prior to 1944 was due to poor soil choice, incorrect planting dates, improper plant spacings and poor fertilizer and cultivating practices. Beginning as early as 1941 and continuing to date, the Federal Government, certain State experiment stations and The Baker Castor Oil Company have conducted research on these and other cultural problems in order that reasonably accurate recommendations on cultural methods could be made to growers. Also, as might be expected, valuable supplementary information on these points has come from close observation of the hundreds of commercial fields since 1947.

Variety Development. Almost all imported castor beans, when planted anywhere in the United States, produce plants which are unacceptable for commercial production because of one or more of three main factors: (*a*) excessive plant height and stem size, (*b*) shattering of each capsule at maturity, and (*c*) low yield. In order for castor beans to be produced efficiently in this country, it was essential that varieties be developed that are suitable in all of these three characters.

Whereas it is possible that the types used in the 1800's would be acceptable today in yield and even plant size, it is certain that their characteristic of shattering, which was necessary then without hulling machinery, renders them unacceptable today.

The World War I effort failed to produce a good agronomic plant type. Between the First and Second World Wars the Federal Government selected some fine-stemmed varieties from seed supplied by The Baker Castor Oil Company. During that same time, Professor John W. Gilmore of the California Agricultural Experiment Station made a great number of introductions from many parts of the world. As will be noted below, much of the current domestic production has been made possible by varieties developed later from these introductions by Professor Gilmore.

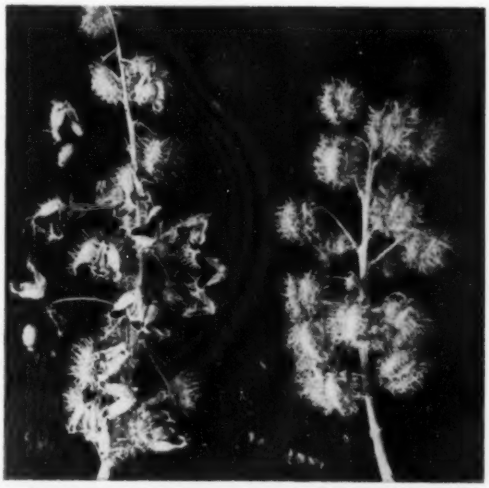


FIG. 1 (*Upper*). Single spikes of shattering and shatter-resistant varieties of castor bean.

FIG. 2 (*Lower*). Single plant of dwarf castor bean variety for interior irrigated valleys of California and Arizona.

In World War II a great many small lots of seed were collected from many sources in this country. The Federal

and State agricultural research agencies tested them as extensively as the amounts of seed permitted. All but three were discarded as being unsuited for commercial use, and seed stocks of those three were increased and used by the Federal Government in the World War II production program. One of those, Conner, has been used in the early years of the current production program, but it is giving way to varieties which are superior in shatter-resistance, earliness and yield.

It was not until the 1940's that organized technical breeding was conducted with castor beans. Because of the time required for breeding new varieties, this work was not productive sufficiently early to be of benefit in the Second World War. Shortly after the close of the war, varieties began to be released by different agencies. These new varieties have usually enjoyed short terms of use because superior new types are quickly and continually being developed.

Possibly the most productive breeding program to date has been that of the Chemurgy Project of the University of Nebraska. Since the early 1940's, under the direction first of Dr. Carl Claassen and later of Mr. Albert Hoffman, this program has worked toward the goal of acquiring varieties with exceptional shatter-resistance, earliness, yield and plant form. Much of that material is the result of selection and purification either of plants found in Professor Gilmore's material or of plants which these workers produced by chance or controlled hybridization. Two early inbred varieties produced by this program and which have been used commercially are known as Nebraska 108–3 and Nebraska 201–2. Currently their Cimarron variety is very popular in Oklahoma and Texas. These workers also made first note of plants with little or no pollen, and of the possible use of this character in the production of hybrid castor bean seed for commercial use. Currently that project has on trial several hybrid castor bean strains which have sufficient promise that commercial use of castor bean hybrids seems to many people to have already been proven feasible.

The original breeding research of the United States Department of Agriculture began in 1943 under the direction of the writer and continued, starting in 1947, under Dr. D. L. Van Horn. By 1947 that program produced a few varieties, including variety USDA #74 which is still in use in Oklahoma and Texas. That research program has recently been enlarged, and many good varieties for both the Midwest and the Southwest have been bred and are now being tested against the standards. The Midwest portion of this research has recently been done in cooperation with the Oklahoma Agricultural and Mechanical College, where it replaced a three-year joint breeding program by The Baker Castor Oil Company and that College. The Southwest portion of this research is conducted at both Shafter and Brawley, California.

The University of Illinois has had a small breeding program since 1941. Sponsored by Dr. W. L. Burlison, the work was carried on first by the writer, and has been continued since 1943 by Mr. Roland Weibel. It seems that the Illinois research might be effective in extending the area of best adaptation eastward to include at least part of that State.

Dr. Paul F. Knowles, of the California Agricultural Experiment Station, recognizing the value of Professor Gilmore's materials, has recently planted all of the remnants of those seed stocks, evaluating and selecting within those plantings. Some promising inbred varieties have now reached the stage of variety testing. Mr. L. G. Goar, then of the California Agricultural Experiment Station, made some selections in the earlier

FIG. 3 (*Upper*). Field of dwarf castor bean in the Imperial Valley of California.

FIG. 4 (*Lower*). Massey-Harris castor bean combine harvesting capsules from a dwarf castor bean variety in the Yuma Valley of Arizona.

1940's from Professor Gilmore's materials, planted them in the Imperial Valley and made some open-pollinated selections within them.

The Baker Castor Oil Company, starting in 1947 with Mr. Goar's selections, bred varieties known as Baker #1, #7, #34 and #195, which four varieties made possible the first successful commercial production of castor beans in California and Arizona. These four dwarf varieties, adapted only to irrigated lands, are early-flowering and are sufficiently shatter-resistant and small in stature that they require only a single harvest at the end of the season, that harvest being by machine.

Engineering Research

Harvesting Equipment. The Agricultural Engineering Department of the Chemurgy Project of the University of Nebraska, from 1946 to 1948, conducted what was probably the first organized engineering research on mechanical harvesting of castor beans. That work [3] by Mr. Milo Arms resulted in the design of a stripping machine for the type of plant grown in the midwestern States. It left the tall unbranched plants standing and beat off the capsules. The machine also cleaned extraneous materials from the capsules and elevated the capsules into a storage bin which was periodically discharged at the edge of the field. The first machine was a one-row, power take-off, pull-type. The Baker Castor Oil Company was licensed to have machines made, patterned after this experimental model. Eleven such machines were made for Baker in 1947 and 1948. They were leased and later sold to Baker's contract growers, with the exception of the donation of one each to the University of Nebraska and the United States Department of Agriculture for further research.

In 1950 and 1951 the Bureau of Plant Industry, Soils, and Agricultural Engineering of the United States Department of Agriculture redesigned this stripper as a tractor-mounted machine; first as an experimental one-row model, later as a two-row model. The Commodity Credit Corporation had 60 of the two-row tractor-mounted type manufactured in mid-1951 for use on part of the some 56,000 acres of 1951 commercial production on dryland in Oklahoma and Texas. Further refinements will no doubt be made in that machine by way of lighter weight and addition of an element for removing extraneous material from the capsules.

Many attempts have been made to harvest castor beans with a conventional combine. The intent has been only to remove the capsules from the plant, and not to remove the hulls from the beans. In all of the early trials, which were made by farmers, owners of custom equipment and implement companies, the machines were tried without major modifications, and the results were consistently unsuccessful. The major difficulty was loss of seed capsules in front of the header.

In 1949 the Massey-Harris Company began some intensive research along the lines of modifying and adapting their conventional Clipper combine to the harvesting of castor beans. That work, under the direction of Mr. Harry Smith [4], resulted in the design of a special castor bean attachment which replaces the conventional reel and sickle. The attachment is constructed so as to reduce to a minimum the serious loss of capsules which had been experienced earlier with unmodified equipment. Four Massey-Harris castor bean harvesters were in commercial use in 1950, and an additional 54 were manufactured and put in use in 1951. The machine is be-

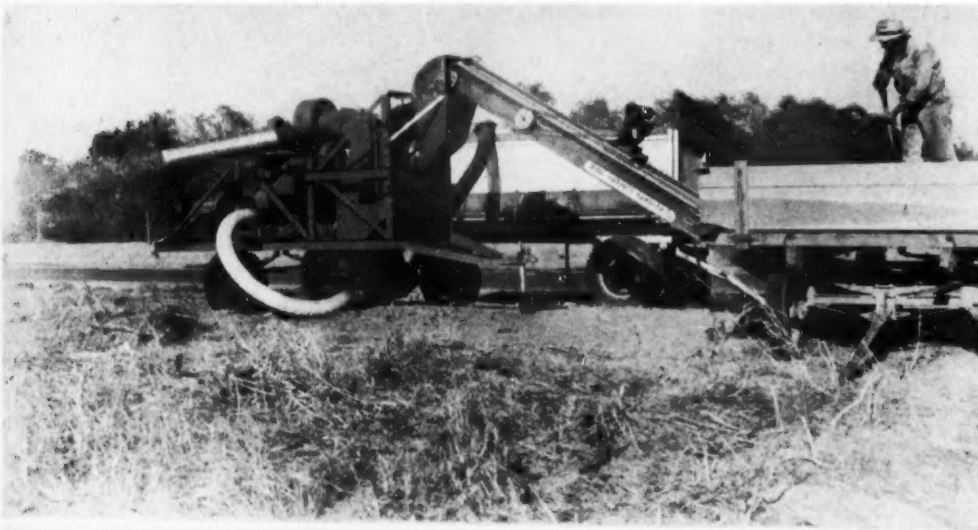
[3] Certain funds for this work were contributed by Nathan Gold, Lincoln, Nebraska, and The Baker Castor Oil Company.

[4] Valuable contributions were made by F. W. and Wendell Callahan, El Centro, Calif.

ing used exclusively on the bushy type of plant grown on irrigation in California and Arizona, and in those areas of Oklahoma and Texas which have irrigation.

Hulling Equipment. The development of shatter-resistant types, which permit a single fall harvest either by hand or by machine, required the development of mechanical equipment for removing the hulls. A great variety of ideas have been tried, but only two basic principles have reached the stage of being incorporated into commercial hulling machines.

The castor beans from the Federal Government's World War II acreage



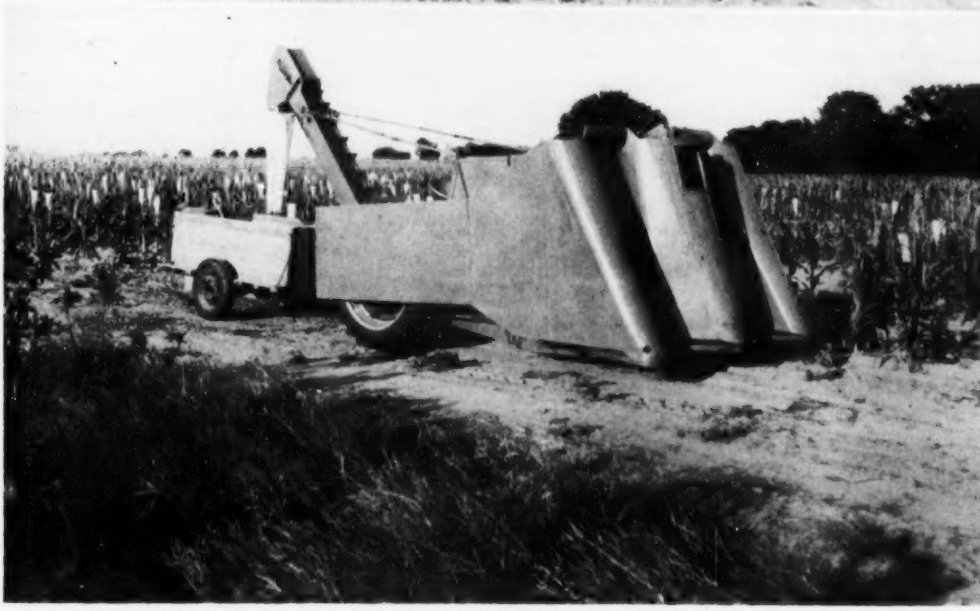


Fig. 5 (*Upper*). Castor bean huller operating at field edge in Arizona.

Fig. 6 (*Lower*). Castor bean stripper harvester made by the United States Department of Agriculture after the Nebraska principle.

were purchased in-the-hull, and the United States Department of Agriculture designed a machine for hulling that production. The hulling element was a rubber-faced cylinder turning inside a rubber-faced concave. Several of these cylinder-type hullers were manufactured and used during the Second World War. In 1947 The Baker Castor Oil Company had an additional 15 machines manufactured for use in the early years of its domestic production program.

Early in the 1940's the Tennessee Agricultural Experiment Station, in cooperation with the Tennessee Valley Authority, designed a castor bean huller. Several of these machines were manufactured in the 1940's and sold to both American and foreign purchasers. The hulling element in the Tennessee machine is a pair of opposing rubber-faced discs, one stationary and one rotating. The beans-in-hull are fed between these discs through an opening in the center of the stationary one. The hulls are rolled off the beans as they pass radially outward between the two discs.

Starting in 1949 The Baker Castor Oil Company designed a huller embodying some new ideas along with the better elements of several existing machines. Certain redesign was made in both 1950 and 1951. The Baker huller, because of its greater capacity, hulling performance and structural design, is now being used almost exclusively on the present production in the United States.

In California and Arizona, because of larger operations and drier atmospheres, hulling is done at field-edge concurrent with combine harvesting. The combine periodically discharges its collection of beans-in-hull at the huller. The clean beans from the huller are loaded into trucks. The hulls, having good fertilizer value, are returned to the land.

In the Midwest, growers take their beans-in-hull to stationary hullers located centrally in each production area. This system has been adopted because of smaller production per farm, weather conditions not always permitting hulling concurrent with harvesting, and hand-harvesting by some growers which extends the hulling over a longer period of time.

No immediate change is anticipated in these two diverse types of hulling operation in the Southwest and the Midwest. It seems probable, however, that in areas where hulling can be performed along with harvesting, the hulling equipment will soon be attached to the harvester.

Conveyors. Castor beans present unusual problems of conveying because they are brittle, their contents are very oily, and any breakage causes accumulations in the conveying equipment and results in deterioration of the oil. The Baker Castor Oil Company has made some special equipment for conveying castor beans. One conveyor is a drag-type using a troughed canvas. Another utilizes a pneumatic system, picking up beans under suction and discharging them under pressure.

Development of Marketing Methods

In the absence of domestic production there was no established procedure for grading or purchase. Further, the poisonous nature of castor beans, as well as the unusual conveying problem which they present, precluded the use of conventional marketing facilities without special precautions and alterations.

Grading Procedures. None of the factors of moisture, cracked beans or beans-in-hull has to date been considered in purchasing foreign beans because the shattering nature of those varieties and the methods of handling the foreign production are such that these factors are kept to an acceptable minimum. With mechanical harvesting and hulling, however, these factors can attain objectionable proportions. In contracting with its growers from 1947 to date, The Baker

FIG. 7 (*Upper*). Hulling center in Texas where growers' beans-in-hull are brought for hulling.
FIG. 8 (*Lower*). Pneumatic conveyor designed especially for castor beans.

Castor Oil Company has developed a procedure of grading which has proven acceptable to both grower and buyer. In addition to free foreign material, the grading involves factors of moisture, cracked and broken beans, and the hulls still remaining on good beans. The deduction to the grower for excessive amounts of these factors is on the basis of pounds rather than price.

Purchase Procedures. Production under grower contracts with The Baker Castor Oil Company since 1947 has resulted in the development of two patterns of purchase. In the irrigated valleys of the southwestern States the crop is harvested and hulled by either grower-owned or custom-operated machines. The grower delivers his clean beans either direct to the buyer's oil mill by truck, or by truck to a consolidation point, thence to the mill by rail. The grower's individual truck deliveries, either at the oil mill or at a consolidation point, are weighed and sampled. The grower is paid on the basis of his delivered weight less poundage deductions as a result of the quality of his delivery.

In the midwestern States the grower brings his beans-in-hull, whether harvested by hand or by machine, to the nearest " hulling center " where the hulling is done at a fee to the grower. To date these hulling centers have been owned and operated by the contract buyer of the beans. The buyer has been The Baker Castor Oil Company; however, in 1951 a small part of the production was purchased and hulled in this manner by the Commodity Credit Corporation. The hulling equipment includes sampling equipment and scales. Title to the beans transfers from grower to buyer at hulling time. The grower is paid on the basis of his weight of beans from the huller less deductions for his grade. The clean beans are either loaded directly in boxcars for shipment to the oil mill or are stored temporarily for later rail shipment.

Commercial Production

Whereas each of the research and development programs outlined above was essential to the establishment of castor beans as a farm crop, they did not individually or collectively create commercial production. Four additional types of work were necessary to get the crop grown. They were seed increase, publicity, assurance of a fair market to growers, and technical service to growers.

Seed Increase. Taking the minute quantities of seed of the new varieties developed by the Federal, State and its own breeding programs, The Baker Castor Oil Company increased those seed stocks under conditions which would prevent cross pollination with other varieties, wild plants or dooryard ornamentals. This increase was usually done concurrently with evaluation of the same varieties in variety tests so that at least some planting seed would be available of whichever varieties were demonstrated to be best. Seed stocks of the best varieties had to be increased further before the acreages could be counted in the thousands.

Publicity. In the period of prosperity and unrestricted acreages of common crops following World War II, the attitude of many farmers was to let someone else make the first trials with this new crop which required some special equipment and about which they knew nothing in regard to either production procedures or market possibilities. It was necessary to acquaint several thousand farmers in select areas with the place, both immediate and potential, that castor beans have in their farm operations. Each one needed to be shown that, in growing castor beans, he would be producing a versatile oil for a variety of industrial uses, not a cathartic for the druggist's shelf. He needed to be shown

that the researchers had produced acceptable varieties, agronomic know-how, marketing methods, and harvesting and hulling machinery—and also that this special machinery would be manufactured and available when he needed it.

In the early years very little assistance along these lines came from the agricultural extension services of the State and Federal governments, since the crop was equally new to them as it was to the grower. This vital and difficult work was all done in the early years by the contract buyer of the beans, which was The Baker Castor Oil Company. As of the present, however, several Federal and State offices are making material contributions in providing information on castor beans to the farming public.

Contracting. In order to assure the grower that he would have a market at the end of the season, The Baker Castor Oil Company, and in 1951 the Federal Government to a smaller degree, wrote production-purchase contracts with all growers prior to planting time. Not only did that contract assure the grower a market for his production, but also it provided a minimum selling price. In 1951 that minimum selling price was guaranteed by the Federal Government and was substantially greater than the earlier guarantees. This higher guaranteed price contributed to the increased 1951 acreage.

Technical Service. In each area of its contract production The Baker Castor Oil Company provided technically trained personnel to advise the contract-growers throughout the season on problems of soil choice, growing procedures, and harvesting and hulling methods.

Conclusions

It is obvious from the foregoing discussion that many of those factors which once were deterrents to domestic castor bean production have been removed. Their removal is the result of outstanding contributions by many individuals and agencies. Those contributions have been correlated and supplemented in a manner which has added castor beans to the list of cash crops for farmers in this country.

Further developments and improvements will be made and they will increase the efficiency of domestic castor bean production. That increased efficiency is expected to lower the production costs of castor beans, which, in turn, will further increase the total domestic acreage by increasing industrial consumption of castor oil and its many derivatives.

Utilization Abstracts

Guayule. Rubber in guayule (*Parthenium argentatum*), as in other rubber-bearing plants, is present as latex, but the latex is not in ducts that can be tapped; it is contained in discrete cells. Extraction of the rubber has always presented problems in commercial exploitation of this source, and storage of the harvested material has been regarded as necessary in order to bring about coagulation before mechanical extraction. It has now been found that coagulation of the latex in fresh guayule may be brought about by parboiling and mechanical treatment. (K. W. Taylor and R. L. Chubb, *Ind. & Eng. Chem. 44(4): 879. 1952*).

Cortisone from Yucca. A factory at McConnico, Arizona, processing yucca fiber, may find a valuable by-product in the 300,000 pounds of leaf powder which it can produce monthly, for chemists at the Eastern Regional Research Laboratory have found that the powder contains 0.5–1.0 percent of a steroid, sarsasapogenin, which is being investigated as a potential precursor for conversion into cortisone. (*Chemurgic Digest 11(9): 8. 1952*).

Production and Utilization of White Potato Starch[1]

About seven percent of the annual American potato crop, or 25,000,000 bushels, is converted into potato starch by 21 factories in Maine and six in Idaho, with a combined capacity of annually producing about 150,000,000 pounds of starch, used principally in sizing textiles but also in the manufacture of paper, food products and adhesives.

R. H. TREADWAY
Eastern Regional Research Laboratory[2], *Philadelphia 18, Pennsylvania,*

Introduction

The potato (*Solanum tuberosum*) is the most important vegetable grown in the United States from the standpoints of both tonnage produced and dollar value of the crop. About 75 percent of our potatoes are used for food in the fresh and processed forms. Approximately ten percent of the annual yield is required for seed for the succeeding crop. The remaining 15 percent is made up of sub-standard potatoes that are unsuitable for the tablestock market because they are too small, too large, misshapen or damaged. These culls are available for feed and industrial uses. In addition to the culls, surplus potatoes are utilized in non-food outlets during large crop years.

Livestock feeding is the largest single outlet for cull and surplus potatoes, consuming one-half to two-thirds of the total utilized in non-food channels. Most of the remaining cull potatoes are used to produce starch.

Potato and wheat were the leading domestic starches early in the nineteenth century. The first potato starch plant in the United States was established in 1831 at Antrim, New Hampshire (2). By about 1880 there were more than 150 potato starch factories operating in Maine, New Hampshire, Vermont, Michigan, Wisconsin, Ohio and Minnesota (4). The industry, from its early history up to the present, has been made up of numerous small plants instead of several large factories, as we find in cornstarch manufacture. In Maine and other States, special varieties of potatoes were grown for starch manufacture. These varieties were not of outstanding culinary quality but contained a relatively large amount of starch. In the Netherlands and Germany different types of potatoes are still grown for tablestock and for industrial uses.

Late in the nineteenth century potato starch lost its strong position in the general field to cornstarch, which could be sold at a lower price. Potato starch then entered the category of specialty starches.

Corn has several economic advantages over potatoes as a raw material for starch manufacture in the United States. Potatoes will equal or exceed corn in yield of starch per acre, but corn can be produced cheaper because it is better adapted to mechanized methods of farm-

[1] Article received for publication February 7, 1952.

[2] One of the laboratories of the Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration, U. S. Department of Agriculture.

ing. Corn dries out to 12 to 15 percent moisture content in the field. In this condition it can be shelled, easily transported and stored before processing. Potatoes are about four-fifths water, which adds materially to the bulk and weight in transportation. While potatoes are sufficiently perishable to require special methods of handling, corn is easily stored in elevators from which large factories can draw their raw material throughout the year. Potato starch factories usually operate only about eight months of the year, from October through May. The corn wet milling industry has valuable byproducts, such as oil and gluten feed, which aid in making the industry profitable. The potato starch industry, on the contrary, has no byproduct except the extracted pulp which a few manufacturers recover and sell as feed.

By 1900 the number of potato starch factories had decreased to 63 (2). A decided trend developed toward concentrating the potato starch industry in Aroostook County, Maine, where 45 of the nation's plants were located. Northern Maine became a center for production of tablestock and seed potatoes, with the starch industry providing an outlet for the culls. In 1920 there were about 20 factories in Maine with a combined daily capacity of somewhat less than 75 tons of starch. Although the total productive capacity of Maine's starch industry has increased markedly since that time, owing to the construction of new plants and modernization of existing facilities, the number of plants has remained nearly the same.

The history of American potato starch thus consists of three phases:

1. The period from about 1850 to about 1900, in which it was a leading all-purpose starch.

2. The period from about 1900 to late in the 1930's, when it was a specialty starch greatly overshadowed by corn and tapioca starches in the general field. During this interval much of the high quality potato starch used by American industry was of necessity imported.

3. The recent period in which such an upsurge occurred that the annual production figure was tripled in about 15 years. A revival in the general usage of this starch has made it competitive with cornstarch, to a certain extent, in several applications. However, it still must be kept in mind that approximately ten times as much cornstarch as potato starch is used.

Statistics of Production

At present there are 21 potato starch plants in Maine, having a total capacity for producing about 225 tons of starch a day, or 90 million pounds in a 200-day operating season.

Potato starch production was inaugurated in Idaho late in 1941 with the establishment of plants at Blackfoot and Twin Falls (1). In 1942 a third plant was built at St. Anthony. The fourth plant for the State was established at Menan in 1944 but was later moved to Idaho Falls. Developments in 1948 included the construction of an additional plant at Idaho Falls, the rebuilding of the Twin Falls plant and conversion of a glucose sirup plant at Jerome to starch manufacture. The new Twin Falls plant has the largest capacity of any potato starch factory in the United States. Two-thirds as much starch can be produced in the six Idaho plants as in all of Maine's factories. Thus the entire American industry can turn out about 150 million pounds of starch annually, as it did during the 1950–51 season.

Method of Production

Although disadvantages were pointed out in the storing and handling of potatoes relative to corn, potatoes are definitely easier to process for starch recovery. In the wet processing of corn, the grain must be " steeped ", *i.e.*, soaked for

about 48 hours in warm water acidified with sulfur dioxide. Steeping is necessary primarily to soften the kernel so that the various constituents may be separated. Corn must be passed through a special mill to remove the germ of the kernel. The degerminated corn is then passed through buhr mills to disintegrate the tissue and permit separation of the fiber from the starch and gluten.

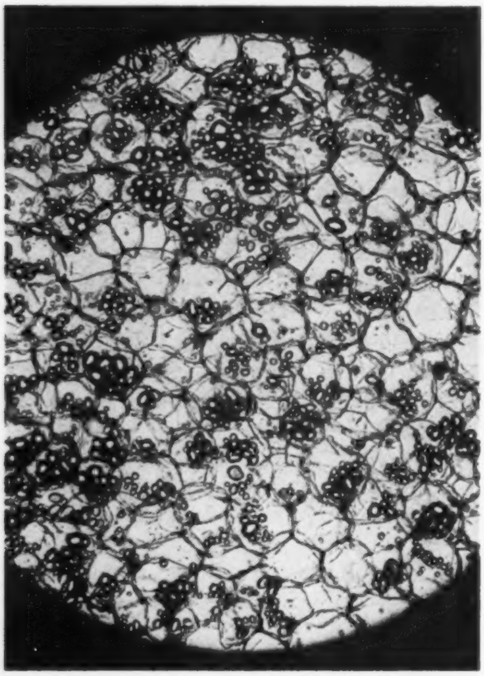


FIG. 1. Section 120 μ thick sliced from the pithy area of raw potato tuber. Magnification, 52 ×.

Potatoes are milled directly after leaving the washer. Either a rasp or a hammer mill is used to disintegrate the potato cells and liberate the starch. The skin and fiber are then separated from the starch by screening. Final purification is similar in both corn and potato starch manufacture. Removal of the water solubles is effected by washing, and the remaining insoluble impurities are separated from the starch by means of specific gravity difference.

A photomicrograph of potato tissue is shown in Fig. 1. The cross section is from a low-starch potato sliced from the center of the tuber, where the starch content is quite low. In this particular section the tissue contains only perhaps five percent starch. However, for the purpose of illustrating how potato cells are grouped together and the manner in which starch granules are packed in the cells, it is preferable to examine a section containing relatively little starch. The walls of potato cells fit closely to one another with only occasional air spaces, in a pattern similar to a honeycomb cross section. The several more tightly packed cells shown in the illustration are typical of potatoes used in starch manufacture.

A typical Maine factory produces about ten tons of starch a day while consuming 80 to 90 tons of potatoes. The average composition of potatoes processed in Maine factories is estimated as follows:

TABLE I.

AVERAGE COMPOSITION OF POTATOES PROCESSED IN MAINE STARCH FACTORIES

Substance	% present
Starch	13
Protein (NX6.25)	2
Cellulosic material	1.5
Sugars	0.5
Mineral (ash)	1
Miscellaneous minor constituents (total)	1
Water	81

Potatoes received by the Idaho starch plants contain perhaps 15–16 percent starch.

The process used in one of the modern plants is illustrated in Fig. 2 and outlined in the following description [3]. The

[3] For a more complete discussion and operating data on potato starch processing, see Howerton, W. W., and Treadway, R. H., Manufacture of white potato starch, Ind. and Eng. Chem., 40: 1402–1407 (1948).

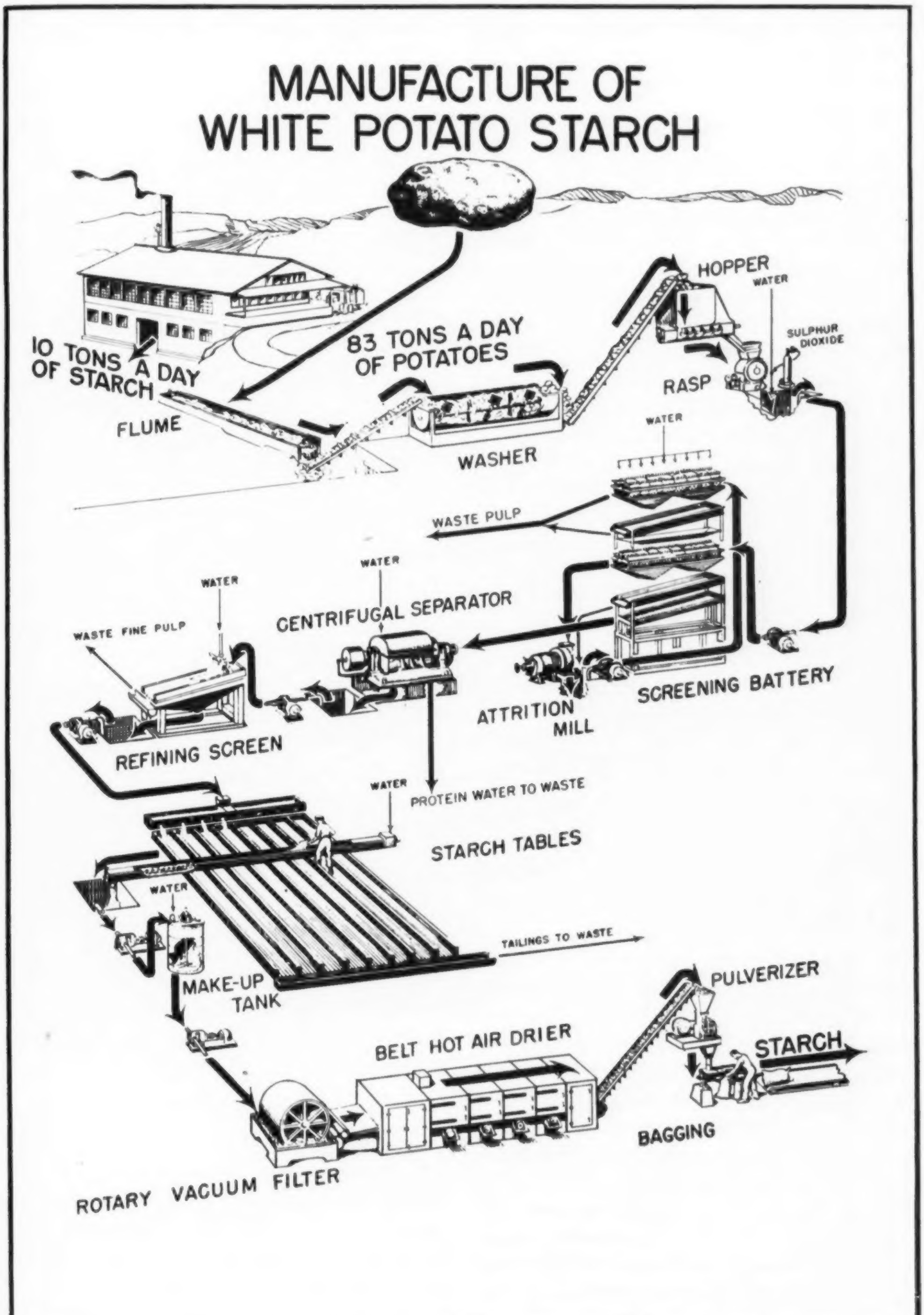


FIG. 2. Flow diagram for manufacture of white potato starch as carried out in a modern factory in Maine.

methods and equipment used in other modern factories differ in some ways from those given here, but the general steps are similar.

Starch plants in Maine have storage facilities for handling 10,000–12,000 bushels of potatoes at the factory. The potatoes are removed from the storage bin by way of a flume which carries them to a conveyor and at the same time removes stones and much dirt. The conveyor lifts the potatoes up to the washer, where the remaining dirt is removed. The potatoes are then elevated to a hopper from which they fall to a screw conveyor that regulates the raw material flow to the rasp. The rasp reduces the potatoes to a slurry. The slurry is diluted with water to facilitate subsequent screening. Sulfur dioxide is added at this stage to inhibit the action of oxidative enzymes and thereby aid in producing a white starch. The dilute slurry is pumped to a battery of screens on which most of the cellulosic material is retained while the starch passes through.

The screening battery consists of screens and sieves mounted vertically in the following order: Lower shaker screen (80-mesh), lower rotary brush sieve (perforated with 0.03″ diameter holes), upper shaker screen (100-mesh), and upper rotary brush sieve (perforated with 0.02″ diameter holes). In the screening operation the starch is first pumped onto the bottom sieve. Here the starch and water pass through and the pulp is discharged off the end of the sieve. The pulp is diluted with water and drops into an attrition mill for a second grinding to release a further quantity of starch. The starch suspension, with the fine pulp that passed through the lower sieve, falls onto the lower shaker screen. The starch granules pass through and most of the fine pulp is discharged from the end of the screen later to be mixed with the reground pulp from the attrition mill. The combined pulp is then pumped to the upper sieve where it is washed with a water spray. The fine pulp and starch pass through this sieve and drop onto the upper shaker screen. The starch suspension passes on through to the lower shaker screen. The fine pulp from the upper shaker screen and coarse pulp from the upper sieve are joined to constitute what is called the pomace or waste pulp which is discharged to the sewer.

The starch suspension from the screening battery is then pumped to a centrifugal separator where the "protein water", *i.e.*, wash water containing the soluble materials, is removed. The starch from the continuous centrifuge is diluted with water and pumped to a refining screen (120-mesh) which removes additional fine pulp. The starch suspension is then pumped to tables where the starch settles and the remaining traces of fiber and soluble substances flow off at the end.

The starch cake scraped from the tables is then diluted to the proper density for pumping to the continuous rotary vacuum filter. After dewatering to about 40 percent moisture, the cake is dried in a continuous belt drier to about 17 percent moisture (3).

The finished starch has approximately the following percentage composition on the dry basis: starch, 98 to 98.5; ash, 0.3; cold-water-soluble compounds, 0.1. It contains about 0.5 percent fibrous material and traces of nitrogen compounds and sugars.

Utilization

Maine potato starch is used in its various outlets in approximately the following proportions, expressed in percentages[4]: textiles, 42; paper, 28; food uses, including thickeners and confections, 14; adhesives, 10; miscellaneous, 6.

[4] Obtained from M. C. Bartlett, Maine Institute of Potato Starch Manufacturers, by correspondence, November 13, 1950.

During the period prior to World War II domestic potato starch nearly always sold at a higher price than cornstarch. Imported potato starch at times sold at about twice the price of domestic cornstarch (4). For many years this price relationship confined the use of potato starch to special applications in which its unique properties make it preferable. 1937, however, was about 2.4 billion pounds, including 1.5 billion pounds used for glucose sirup and sugar manufacture. The remaining 0.9 billion pounds was used for export and manufacture of dextrins and modified starches.) The demand for domestic potato starch in 1937, however, was sufficient to result in the sale of only 17 million pounds of starch.

FIG. 3. A potato field in flower in Aroostook County, Maine. (*Courtesy Rohm and Haas Company*).

The availability of imported tapioca starch at a price generally competitive with corn starch was another factor limiting the demand for potato starch during the decade preceding World War II. Tapioca imports reached the high level of 433 million pounds in 1937, which can be compared with 685 million pounds of cornstarch sold that year in the United States for use as starch (4). (The total cornstarch production in

Most of the tapioca starch used in the United States during the 1930's was imported from The Netherlands Indies. In fact, a high percentage of the total tapioca starch exported from that country at the time was shipped to the United States. Outbreak of the war in the Pacific late in 1941 cut off imports from this source. Fortunately our domestic white potato starch industry began expanding and modernizing in 1938 and

was thus able to meet increased demand for its product. As a result potato starch production was increased to furnish a sufficient supply of this starch for the most essential uses and to replace in part the unavailable imported root and tuber starches.

Since the close of World War II, some tapioca starch has been imported from Brazil and Santo Domingo, but this starch has not resumed anything like its former position.

For the past three years potato starch and cornstarch have sold at five and one-half to seven cents a pound delivered to eastern cities; at times potato starch has even been cheaper. This favorable price situation, coupled with the industry's successful effort to assure a continuous supply of high grade product, has increased the general use of potato starch.

Textiles. More potato starch is used in the sizing of cotton, worsted and spun rayon warps in the textile industry than in any other single application. In warp sizing, parallel threads that run lengthwise in the loom dip into a bath of hot starch paste formulation; the sized thread passes over heated drums to effect drying after leaving the bath. The function of warp sizing is to bind tightly the loose fibers to the surface of the thread and thereby strengthen and protect the warp from abrasion during weaving. "High count" warps, containing many individual fibers spun together, are difficult to size because of small interstitial space betwen the fibers. Potato starch is preferred to cereal starches in warp sizing because its paste penetrates farther before gelling. Deeper penetration of the starch results in formation of a film that adheres well to the warp and consequently gives it more strength and resistance to abrasion. It is well known that potato starch films have a high degree of toughness and flexibility relative to other starches. This permits potato starch sized warps to be woven at lower humidity than those sized with cornstarch.

The smooth clear pastes obtained with potato starch also have other advantages in warp sizing. Cereal starch pastes frequently contain large aggregates of gelled material which stick to the warp and subsequently get caught in the loom to cause thread breakage. Potato starch sized warps not only have a smoother finish but also are easier to de-size after the size has served its purpose. The lesser tendency of potato starch pastes, in comparison to cereal starch pastes, to "set back" or retrograde to a gel is of advantage following shutdowns. It is also claimed that less tallow is required in potato starch sizes to minimize sticking of warp to drying drums than with other common starches. Potato starch is said to be superior for sizing warps that have been previously dyed in that it gives a brighter color.

The finishing of cotton sewing thread is similar to warp sizing. The thread is immersed in a finishing bath and then passed over brushes to provide a smooth finish. Many manufacturers of cotton thread, like textile manufacturers in their warp sizing, use potato starch exclusively.

Potato starch is not outstanding in its ability to bring out color intensity of vat dyes when used as a thickener for textile printing pastes, but it possesses superior properties as a finishing agent. Cloth finished with potato starch has a better "feel" and smoother surface than obtained with cereal starches.

Paper. Although it has long been known that potato starch has valuable properties for many applications in paper manufacture, its use previously was not common, even in mills in starch-producing areas. During the past few years, however, expanded use in the paper industry has been the leading potato starch development.

Starch is used for four purposes in paper manufacture: (*a*) beater sizing in which the cellulosic fibers are cemented together preparatory to sheet formation; (*b*) tub sizing, in which the preformed sheet is passed through a dilute size solution; (*c*) calender sizing, in which a smooth finish is imparted; and (*d*) surface coating, which is an optional step in finishing high-grade papers. Starches and dextrines are also used in combining and sealing paperboard in the fabrication of folding, corrugated and laminated solid-fiber boxes.

Cold-water-soluble potato starch is outstanding in its performance in beater sizing. This modification is produced by cooking a suspension of the starch, drying the paste on drum driers, and grinding the flakes to a powder. This type of soluble potato starch was first manufactured in Holland and has been produced for years in this country to supply a steady market. Soluble potato starch or " gum " is preferred to the corresponding products from other starches in beater sizing because its paste possesses great stringiness and cohesive strength. Furthermore, these properties are said to be affected relatively little on addition of alum. Alum is regularly used in paper manufacture, and its acidic character is detrimental to the properties of most starch pastes.

FIG. 4. Harvesting potatoes in Aroostook County, Maine. (*Courtesy Rohm and Haas Company*).

Food. Much of the potato starch utilized in the food industry is used in bakers' specialty items, such as Swedish and German style breads, in crackers

and in matzoth. It is also used as a thickener in soups and in gravies. Potato starch has been pelleted successfully to make puddings similar to those ordinarily made from tapioca starch. Although potato starch puddings were rather well received during the last war when tapioca was unobtainable, the food trade seems to prefer tapioca puddings. As a result the use of potato starch in puddings is at present rather limited.

Starch is used in the confectionery industry for the following purposes: (*a*) as a medium for molding cast candies such as jelly beans, " orange slices " and gum drops; (*b*) as a bodying agent and to impart smoothness and stability to caramels and marshmallow; (*c*) as a thickening agent in synthetic jellies; (*d*) as a dusting agent, perhaps mixed with powdered sugar, for candy gums, chewing gum, etc. Thin-boiling starch (treated to reduce its paste viscosity) rather than thick-boiling starch (unmodified) is ordinarily used as an ingredient in candy manufacture. Starch constitutes 10–12 percent of the total weight of dry ingredients in candy gums. Glucose sirup produced by the hydrolysis of starch is widely used in candies, beverages, chewing gum, ice cream and confections in general. Very little potato glucose sirup is being produced at present; during World War II, however, when corn, beet and cane sirups were under allocation, several plants made potato sirup.

FIG. 5. Harvesting potatoes in Aroostook County, Maine. (*Courtesy Rohm and Haas Company*).

Adhesives. In producing adhesives it is generally advantageous to modify starch by chemical or physical treat-

ment to reduce its paste viscosity, thereby permitting use of higher solids concentration, and to develop so-called tackiness. Although some potato starch is modified for use in adhesives by treatment with an acid to produce "thin-boiling" starch or with alkaline hypochlorite to produce "oxidized" starch, most of it is used in the dextrinized form for this purpose. Dextrins are produced by roasting starch in the presence of an acid catalyst. It is a well known fact that films of dextrins made from root and tuber starches, such as tapioca, sweet potato and potato, have greater flexibility and resistance to checking than dextrins of cereal starches. Potato dextrins are used in many applications in which their specific properties make them desirable; for example, as a binder in sand paper, abrasive cloth, bookbinding and rug sizing, each of which requires a dextrin of high paste tackiness and of flexible residual film. Potato dextrin films are also outstanding for their ease in remoistening; this property is desired in mucilages used for gumming stamps, labels, envelopes, paper tape, etc.

Miscellaneous Uses. There are a number of miscellaneous uses of starch that cannot be classified under the general categories discussed above. Examples of these uses include utilization of starch as (*a*) hygroscopic addition agent in baking powder; (*b*) fermentation raw material; (*c*) binder for tablets; (*d*) binder and extender for sausages; (*e*) builder for soap; (*f*) separator in dry cell batteries; (*g*) raw material for nitrostarch manufacture; (*h*) consistency stabilizer for oil well drilling "muds"; (*i*) attractant in insecticidal mixtures; (*j*) boiler feed water treating agent; and (*k*) clarifying agent for waters used in mining operations. The miscellaneous uses of potato starch probably include some of these listed. Manufacturers and distributors of potato starch, for business reasons, hold as confidential information concerning some of the lesser uses of their product.

Outlook for Potato Starch

The potato starch industry has made great strides during the past 10–15 years in providing its consumers with more and higher quality domestic starch than heretofore available. The demand constantly exists for large quantities of potato starch. It is impossible to predict exactly how fluctuations in the size of future potato crops may affect starch production. Although smaller potato crops may be in store than the large crops occurring during the last decade, many leaders in the potato industry believe that close grading of tablestock potatoes in the future will assure an adequate supply of culls for starch manufacture.

The potato starch industry reached a high level of production in 1950–51. Since this starch is advantageous for many applications in which it was not previously used, however, further extension of its uses could possibly take place. Greater use in the paper industry in New England and in the Northwest offers perhaps the best opportunity for expansion. Continued growth of the potato starch industry depends primarily upon whether the manufacturers can continue to match the competition of other starches in quality, supply and price.

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Philippine Rubber Plantations

Because of a local law, limiting land operated by any one source of private capital to 2,500 acres, rubber plantations have not been extensively developed in the Philippines, but there are at present seven plantations within this limitation in the islands.

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The Philippine Islands are not major rubber producers, but there are five significant plantations on which rubber is the major commercial crop.[2] All of them are in the province of Zamboanga (western Mindanao) and four are on Basilan Island, just across Basilan Strait from the tip of the Zamboanga Peninsula. The largest postwar planting is on the University of the Philippines Land Grant, a 4160-hectare [3] tract on the north side of Basilan, where about 850 hectares are in rubber trees. All of these are small, but tapping has already begun. The plantation of the Philippine Rubber Project Company (a Goodyear operation) on Mindanao is 1024 hectares, all in rubber. This is the maximum area that can be acquired and operated by private capital under present Philippine land laws. It is a prewar holding, started in 1928, that has been rehabilitated. Some acreage is replanted each year to insure uniform and continued production. The other plantations are of the same size (1024 hectares), but copra and, in one instance, coffee and pepper are also grown. The American Plantation Company, just west of the University of the Philippines tract, is one of the two oldest plantations, but some tracts within it are past their peak production, either because superior stock was not used in the early planting, or because of age of the trees, or the trees are too closely spaced for high yields in this area. The Mongal Development Company on the southwestern side of Basilan Island is comparatively new and seemingly well-managed, the owner obviously having profited by 30 years experience as assistant manager and then manager of the Basilan Plantation Company which is one of the pioneer rubber producers of the Philippines.

Basilan Plantation, a Swiss corporation, first planted rubber experimentally in 1911, and has produced rubber commercially since World War I. It now has 650 hectares in rubber and 350 hectares in coconuts. Since it is the oldest and one of the better of the five rubber producers, it is taken as a representative example of Philippine rubber production. The methods and problems described below, therefore, do not necessarily apply to each of the other plantations.

[1] The writer was aided in this study by grants from the United States Educational Foundation in the Philippines (Fulbright Program) and the University of Illinois Research Board.

[2] In June, 1951, and after this paper was prepared, two government rubber experiment stations (one on Mindoro, the other in Cotabato) were sold to a private concern. Both are reported to have trees of tappable age, so presumably there are now seven commercial rubber plantations in the Philippines.

[3] One hectare equals 2.471 acres.

Physical conditions on Basilan Island are satisfactory but not optimum for rubber production. Most of the island is rolling or hilly upland, and the soils, except in the few small valleys, lack proper native fertility. Mongal has the best soil of the four Basilan plantations. Temperatures are optimum and rainfall is adequate. There is a three-month period that is somewhat dryer but not completely dry, and production appears not to be handicapped by drought. Since the rubber tree is easily damaged by strong winds, the fact that Basilan is rarely crossed by a typhoon is quite significant.

Labor is expensive compared with labor costs in Malaya or Indonesia, but not prohibitive unless crude rubber prices again drop to depression levels. The quality of the labor is considered satisfactory. Mechanics, truck drivers, clerical and supervisory workers are Filipinos.[4] Workers in the factory, warehouse and coagulating stations are Moro-Filipinos. Field laborers are mostly Moros. Tapping is done by the Yakans, a meek, effeminate, semi-primitive, non-Christian group of people who live in western and central Basilan. Yakan men, women and children may wear the native dress of tight-fitting trousers, with leggings of contrasting color or print. Both sexes often wear the hair uncut; women and girls tie it in a knot on top of the head; the men wrap it in a turban. Both men and women are employed as tappers.

Fig. 1. A twelve-year-old rubber tree on Basilan Plantation about two hours after the morning tapping. Note the coconut shell cup into which the latex is flowing.

The rubber tree[5] is tapped the first time when it is about eight inches in diameter. Usually this diameter is attained at six or seven years of age. However, it is uneconomical to begin tapping a given block of trees until at least 50 percent of the trees in the block are large enough to tap. Tappers are paid a flat daily rate for tapping and gathering the latex from an assigned block of trees. The latex flows more

[4] In the Philippines the term "Filipino" is used to connote a member of the Christian faith. Locally, non-Christian residents are never called Filipinos.

[5] A rubber tree is actually composed of three parts. The nursery is planted with seed stock that is indigenous or particularly adapted to the physical environment of the plantation. When the seedling is well started it is severed just above the ground, and a high-yielding variety is grafted upon the young stump; a year later the upper part of the new tree is removed and a disease-resistant top is grafted in its place. Thus a producing rubber tree is composed of a hardy root stock, a highly productive trunk and a disease-resistant top. This practice is probably followed in all areas of plantation rubber.

freely in the early morning; as the day warms up it gradually ceases to flow, and natural coagulation seals the cut. Hence tapping begins by seven A.M., and gathering may not begin before nine A.M. The latex is caught in coconut shells, poured into five-gallon cans and carried by bamboo poles on the shoulder of the gatherer to the roadway; thence taken to conveniently situated field stations where it is acid-coagulated in concrete tanks and subsequently cut into convenient chunks and trucked to the factory. A good tree will yield from 80 to 200 cc. of latex daily, depending on the size of the tree, the skill of the tapper and other factors. This yield compares favorably with the yield per tree in Malaya. The Goodyear plantation in Zamboanga reports a higher yield per tree in the Philippines than is obtained on the Javanese plantations of the same company. About four-fifths of the latex, by weight, becomes coagulated rubber.

Basilan plantation makes only crepe rubber and markets its entire output on the Manila market. It is cleaned, dried and baled into 50-kilo bales. Natural coagulation of latex in the coconut shell cups and along the incision is collected by the tapper, then cleaned and prepared, as is the acid-coagulated rubber.

In summary, it appears that a rubber plantation is a profitable venture in that part of the Philippines which is not subject to typhoons, especially when prices of crude rubber are normal or above normal. During periods of low prices, Philippine rubber probably cannot compete with Malayan or Indonesian rubber, and tapping may be temporarily discontinued until better prices prevail. This has been the practice in the past, as Basilan Plantation Company did no tapping during the period of low rubber prices in the early twenties and again during the early thirties.

FIG. 2. Two factory workers of the Basilan Plantation Company. One holds a chunk of coagulated rubber that has just arrived from one of the field stations; the other has freshly prepared crepe rubber ready to be taken to the drying shed.

Ammi Visnaga Lam.—*A Medicinal Plant*

Extensive investigation has shown that khellin, an active principle obtained from this plant, is of value in treating angina pectoris and bronchial asthma.

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Since ancient times preparations made from the seed-like fruits of this umbelliferous plant have been employed in folk-medicine by the people of eastern Mediterranean countries. Not until recently, however, has the plant attained a relatively conspicuous place as the source of a therapeutic agent. In olden times, and even recently, decoctions prepared from the dried fruits were employed by the people of the Middle East in treating various ailments of the urinary tract. Specifically, this preparation served as a diuretic and to relieve the intense pain resulting from the presence of ureteral stones. Preparations of this drug in the form of a decoction and a tincture were introduced into the Egyptian Pharmacopeia in 1934.

The Plant

Ammi Visnaga Lam., commonly referred to as " khella " by Arabic peoples, can be found growing in many Mediterranean countries. In the United States the species has been sporadically introduced in some sections, including Massachusetts, Pennsylvania, Florida, North Carolina, Alabama, California and Oregon. During the summers of 1951 and 1952 numerous plants were grown successfully in the Medicinal Plant Garden of the Massachusetts College of Pharmacy.

Ammi Visnaga is a glabrous, erect and branching herb which attains a height of two to eight dm. The laminae of the lower leaves are decompound and are deltoid in general outline. They vary in length from five to 20 cm. The ultimate divisions of the leaves are linear to filiform. Cauline leaves are ternately to pinnately dissected. Flowers of the plant are small, numerous and white. They are borne on filiform and unequal pedicels which are spreading at first but rigidly contracted in fruit. The fruits are oblong-ovoid to ovoid cremocarps which attain a width of 1.7 mm. and a length of 2.5 mm. upon maturing. These structures, often referred to in the literature as " seeds ", are glabrous and are flattened laterally. Ribs are acute, and oil tubes (vittae) are solitary in the intervals. Each mericarp (" half-fruit ") shows two vittae in the commissural portion of the fruit wall.

Derivatives

Investigation carried on by numerous research workers has resulted in the isolation of a number of impure as well as pure constituents from the fruits of *Ammi Visnaga*. As is commonly true in such instances some confusion has resulted from the names which have been applied to the derivatives. Some workers have used the term " khellin " when referring to a mixture of principles derived from the khella fruits, and others have applied the name to a different chemical component of the mixture. However,

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Fig. 1. *Ammi Visnaga* Lam. showing the character of the foliage and the inflorescences. Notice that the small white flowers are borne in compact compound umbels. *Courtesy of Smith, Kline and French Laboratories.*

FIG. 2. The dried plant, inflorescence and fruits; also a vial of pure khellin and coated tablets containing this active principle. Khellin is commonly administered in tablet form. *Courtesy of Smith, Kline and French Laboratories.*

khellin (kellin) should be reserved as the designation for the pure derivative known by the following chemical name: 2-methyl-5,8-dimethoxy-furanochromone. It will be used in this sense in the remainder of this paper. "Visammin" has also been proposed as a generic name for khellin, but the latter name continues to be the one more commonly used in the literature.

Other chemical principles have also been isolated from ammi fruits, among them khellol glucoside and visnagin. Khellin, however, is the therapeutically important constituent of this species.

Khellin

Khellin (2-methyl-5,8-dimethoxy-furanochromone) in a pure state is a colorless and odorless crystalline solid, insoluble in cold water but soluble in boiling water, alcohol, acetone and chloroform, and moderately soluble in ether.

When administered to humans and experimental animals it relaxes all smooth muscles, among them those which constitute the walls of the alimentary canal, bronchial passages, bladder, ureters, uterus and blood vessels. Its action is rather prolonged, and its power to produce muscular relaxation explains its value as an antispasmodic in a number of ailments.

Khellin is said to be absorbed rapidly through the mucous membranes of the stomach, small intestine and large intestine following oral administration. The drug is sometimes administered by intramuscular injection. The vasodilating action of khellin appears to be more pronounced on the coronary blood vessels than upon the systematic blood vessels. In proper dosage it also relaxes the muscles of the bronchi.

During recent years extensive pharmacological and clinical studies of khellin have been carried on in this country and abroad. Side reactions that may occur are probably best controlled by proper adjustment of dosage.

These extensive studies have led to the appearance, on the market, of several therapeutic preparations, the products of a number of pharmaceutical manufacturers. These products are intended for use mainly in treating angina pectoris and bronchial asthma. Some workers have suggested the use of khellin in relieving the paroxysms of whooping cough. It must be remembered that use of khellin preparations should be made only under the direction of a physician.

The proprietary names of the khellin products which have appeared on the market, and the companies which manufacture them, are as follows: Eskel (Smith, Kline and French Laboratories); Ammivin (The National Drug Company); Khelloyd (Lloyd Brothers, Pharmacists, Incorporated); and Khelisem (S. E. Massengill Company). All of these products are tablets. Ammivin Injectable (The National Drug Company) is also available.

Utilization Abstract

Akee. Captain William Bligh of Bounty fame originally set out on his ill-fated expedition to Tahiti for the sole purpose of obtaining breadfruit trees (*Artocarpus communis*) to be planted in the West Indies for feeding imported African slaves who labored there on the sugar plantations. He succeeded in this objective on a second expedition, but the Africans preferred fruits from their native lands. One such fruit from the Gold and Ivory Coasts of Africa was known to them as "akee", and when introduced to the West Indies it became a favorite food, not only of the negro population but of the inhabitants as a whole. In honor of the doughty sailor, it was botanically named "*Blighia sapida*". (Lucita H. Wait, *Horticulture 30: 52. 1952*).

Utilization Abstract

Fungal Enzymes. Saccharification of starch, that is, conversion of it into sugar, is an important industrial process and is carried out by means of either acid hydrolysis, using hydrochloric or nitric acid as a catalyst, or of enzymatic hydrolysis with enzymes obtained from plants. The particular enzymes that do this are known as " diastases ", or " amylases ", and they hydrolyze starch to dextrins and two sugars, maltose and dextrose. " These amylolytic enzymes are of two types: The dextrinogenic enzymes, which primarily convert starch to dextrins (carbohydrates intermediate in molecular size between starch and sugar); and the saccharogenic enzymes, which saccharify the higher polymers of dextrose to sugars ".

" Amylases are found in the seeds of such plants as barley, wheat, and soybeans and also in animal glands, such as the pancreas, and in body fluids, such as saliva, blood, and urine. Diastases occur in micro-organisms, such as bacteria and fungi ".

" Of the higher plant sources, barley seed is used most commonly on an industrial scale to saccharify starch. Because activity is enhanced by malting the grain, the seed is steeped in water, allowed to sprout, and then dried. When the grain germinates, the dextrinogenic activity of the material is increased substantially. . . . The germinated and dried barley seed is known as malt. In the fermentation of grain to ethyl alcohol, the conversion of starch to maltose has depended almost entirely on the use of barley malt, at least in this country ".

Wheat and rye malts as well as ungerminated seeds of barley, rye and wheat also contain amylases, and pancreatic diastase is the only amylolytic enzyme of animal origin now used to any extent in industry.

" Fungal enzymes have been used in China and Japan to prepare alcoholic beverages, sauces, and other food products from soybeans, wheat, rice, and sorghum. In general, the products are made by the action of amylolytic and proteolytic enzymes on the starch and protein of the grain or beans. The appetizing aroma and pleasant taste of the sauces and foods are results of the slow chemical changes by which amino acids, esters, and the organic acids are formed ".

" The enzymes are produced by the culturing of molds, usually of *Aspergillus*, on various starchy materials. A mixture of enzymes is made, but amylolytic, or starch-degrading, types predominate. These are most important in the production of saké, Japanese rice wine, for which the rice starch is converted to sugars, which yeast can ferment to ethyl alcohol. The fungal preparation used for starch conversion is known as koji. The use of koji by the Japanese in the production of beverage alcohol is comparable to the utilization of barley malt to make whiskey and beer in this country ".

Several manufacturers in the United States produce what is called " moldy bran " or " mold bran " from wheat bran and *Aspergillus oryzae*. " Mold bran can be used directly as a source of enzymes. It also may be extracted with water, and from the solution a purified and concentrated enzyme preparation can be made. The main use for the saccharifying enzymes in crude mold bran is as the converting agent in the production of ethyl alcohol from grain by fermentation. That use has been advocated for many years, but only in 1945–47 was the material prepared on a large scale for use in alcohol plants. A large amount of mold bran was utilized by a producer of industrial alcohol in the propagation of yeast and for the saccharification of grain mashes ".

" Mold bran could be used to make beverage alcohol. Distillers of whiskey and spirits have been reluctant to use fungal preparations, however, for fear that the flavor and odor of the products might be affected detrimentally or altered markedly. In 1950, no plants were using mold bran as a saccharifying agent in the production of industrial or beverage alcohol ".

" Several factories produce a mold bran and extract it with water for the preparation of refined enzyme products. Purified or refined enzymes are used to prepare sizes and adhesives and to desize textiles. They are used for the clarification of beverages and fruit juices, and in the preparation of table sirup from starch ". (H. M. Tsuchiya and R. H. Blom, *U. S. Dept. Agr., Yearbook 1950–1951*).

BOOK REVIEWS

Jute Substitute Fibres. A. E. Haarer. xxii + 185 pages; illus. Wheatland Journals, Ltd. 1952. 30/-(sterling) or $5. 356 Kilburn High Road, London, N.W. 6, England.

Since time immemorial, two species of jute, *Corchorus capsularis* and *C. olitorius*, have furnished fiber in India and Pakistan for manufacture into coarse clothing and cordage. In the latter half of the nineteenth century, as world trade developed in foodstuffs and other commodities, especially in cane sugar, Bengal was the only part of the world, because of its jute culture, that was able to produce a cheap and suitable fiber in large quantities for making gunny sacks, and since then the world has relied on Bengal jute for bagging material.

More than half the jute of commerce is grown today on a rather narrow strip of country on both sides of the Brahmaputra River in eastern Bengal, the remainder of the crop mostly in the delta of the Ganges. This rather restricted area no longer is able to produce sufficient quantities of the fiber to meet the ever increasing demands of world trade, and suitable additional regions for extended cultivation in India are not abundantly available because the increasing needs for food production in India impose prior claim to such lands. Only in British Guiana and the Amazon region of Brazil have attempts to grow jute on a commercial scale outside India and Pakistan promised success. The result is that commercial interests are now looking toward exploitation of so-called substitute fibers, and it is with these that the present book is concerned.

Of all the plant fibers that have been used by man for ages and have in recent years been investigated as possible fulfillment of the demand for bagging material, only three have shown promise of successful commercial exploitation—Bimlipatam jute (*Hibiscus cannabinus*), roselle (*H. Sabdariffa*) and aramina fiber (*Urena lobata*). The first of these is generally known in American literature as " kenaf ", and under that name it has been extensively discussed in ECONOMIC BOTANY (July–September, 1947); roselle has had similar treatment (January–March, 1949). All aspects of these three fibers are extensively discussed in this latest book on the subject, including their botanical characteristics and distribution; the uses of their fiber and seed; selection and breeding work; climatic, cultural and spacing requirements; harvesting and retting operations; and mechanical extraction of the fiber. At least a dozen other fiber-producing plants are briefly mentioned also as possible jute substitutes, but none of them has revealed the possibilities for commercial exploitation that Bimlijute, roselle and aramina have.

Illustrated Guide to Trees and Shrubs. A. H. Graves. x + 240 pages; illus. Publ. by the author, Wallingford, Conn. 1952. $4.

So many new guides to the identification of plants are published from year to year, sometimes several in one year, that one wonders what each of them can offer that justifies its addition to the already large selection. Plants themselves do not change, and consequently descriptions of them cannot vary much. Where, then, can innovations be made in every new guide? They can be made in illustrations and in arrangement of material to facilitate identification.

Three features of Dr. Graves' new book fulfill these requirements. First, the illustrations are of large size, excellently drawn in considerable detail, and emphasize bud and twig characters, in addition to those of leaves and, in many but not all cases, of fruits. Secondly, it covers native, naturalized and commonly cultivated exotic kinds of trees, a feature of considerable merit, for the rank amateur as well as the advanced amateur is immediately stymied when he unknowingly endeavors, and is frustrated in attempting, to identify some exotic tree or shrub by one of the many manuals devoted exclusively to native plants. Thirdly, a brief chapter, entitled " Short Cuts to Naming ", points out

those features which the expert immediately looks for in making an identification, and which, when spotted, make rapid identification possible, much to the dismay of the amateur who marvels at the facility of his tutor.

Identification of plants, however, cannot be simplified beyond a certain point, and acquaintance with some technical terminology on the part of the reader is unavoidable. In order to use the General Key in this book, for instance, he must know from previous knowledge what is meant by Gymnosperms and Angiosperms. If he does not know, it is of no help to be informed under these headings that in the former group the seeds are naked, borne usually in cones; in the second group, in an ovary. The word "usually" implies that sometimes the seeds are not borne in cones, and it is only the advanced amateur or expert who knows that this vagueness takes care of the fact that among the gymnosperms, the seeds of the genus *Juniperus* are borne in cones which when mature and generally observed are fleshy berry-like structures with no outward resemblance to any cone. Such keys, therefore, are of value only to readers with some background, and others must realize that complete elimination of technical terminology and unavoidable ambiguities would so emasculate a work of this nature that it could not include the wide range of plants which even the rank amateur demands that it cover.

As Dr. Graves explains in the preface, he emphasizes, as he rightly should, those features of leaves, branchlets and winter buds which, with the exception of a short period in May or June, are observable "all the year through" and "at any time of year". An author is usually more aware of omissions from his book than any critic could be, and it undoubtedly was not any oversight but, instead, the problems of modern publication that induced Dr. Graves to omit illustrations of certain very distinctive fruits, such as those of tulip tree, paulonia, sumac and catalpa. These, admittedly, are not noticeable for such long periods as the other features, but they are the strikingly conspicuous objects which often attract the attention of amateurs, which he fails to find depicted in the book and which he then discouragedly discards or brings to someone else for identification, with the cynical comment that none of the guide books is any good. It is therefore earnestly hoped that in a reprinting of this book, which it can hardly escape as a result of demand, an appendix of fruit illustrations, if not inclusion of them in the body of the book, will obviate this possible criticism.

Yuman Indian Agriculture. E. F. Castetter and W. H. Bell. xiv + 274 pages. University of New Mexico Press. 1951.

Fifteen years ago the authors of this volume began collecting field and other data regarding the agriculture of the Mohave, Yuma and Cocopa Indians on the lower Colorado River and the Gila River in southwestern Arizona and adjoining parts of California and Mexico. From 1937 to 1941 they assembled material for the present study and began writing the manuscript in the fall of 1943, but not until 1951 were they able to complete the task. In the meantime, in 1942, they published a similar work on "Pima and Papago Indian Agriculture", thus covering other tribes in Arizona. With these two volumes to their credit, the authors have gone a long way in fulfilling their original intention "to publish a series of comprehensive studies dealing with the early basis of subsistence of the several Indian groups in the Southwest, with special emphasis placed upon agriculture".

In addition to chapters on the country itself, on the people and on their general basis of subsistence, agricultural implements and agricultural techniques, there is abundant information on the vegetation of that desert area and on the cultivated and wild plants utilized by the several tribes. Maize, teparies (*Phaseolus acutifolius*) and pumpkins (*Cucurbita moschata*) were the basic original crop plants among these people; the only other cultivated plants, less important, were cotton (*Gossypium hopi*), bottle gourd (*Lagenaria siceraria*) and sunflower. In addition, however, there was semi-cultivation, for their seeds, of wild plants which also constituted an important source of food and which have been identified as panic grass (*Panicum hirticaule* and *P. sonorum*), foxtail millet (*Setaria italica*), crowfoot grass (*Dactyloctenium aegypticum*) and curlydock (*Rumex crispus*).

The pods of mesquite (*Prosopis juliflora*) and screwbean (*P. odorata*) constituted the chief source of wild food, but in addition there were about 75 other species which furnished edible seeds, greens, fruits, roots, tubers and rhizomes.

The Cultivated Races of Sorghum. J. D. Snowden. 274 pages. 1936. Available from Bentham-Moxon Trustees, Royal Botanic Gardens, Kew, Richmond, Surrey, England. 0.10.6.

In response to a request from the Bentham-Moxon Trustees, ECONOMIC BOTANY is pleased to publish the following announcement of a hitherto unadvertised publication.—Editor.

The importance of this extremely large group of tropical cereals as a source of food for man and beast is now widely recognized by agriculturists and others dealing with world food-shortages. Over large areas of Africa and tropical Asia, the grains of these plants form an important part of the diet of the natives, whilst elsewhere, especially in America and parts of Australia, they are used extensively as food for domestic animals. There are many thousands of local varieties, differing much in structure, yield and growth requirements. Their identification is difficult. It is not generally known, however, that a comprehensive survey of them was undertaken about twenty years ago, when as the result of an appeal issued in the British Commonwealth and in many other countries, several thousand flowering and fruiting heads, together with much valuable data concerning them, were received at Kew. This material was utilized in the preparation of the book entitled " The Cultivated Races of Sorghum ", by J. D. Snowden, at one time Economic Botanist in the Uganda Protectorate. In its 274 pages this book includes not only a classification and descriptive account of the 31 botanical races and of their numerous varieties and forms, but also detailed information on their distribution, culture and economics, together with an extensive bibliography of twelve pages, indices of botanical and vernacular names, and numerous illustrations. It is a work which should be in the libraries of all agricultural officers dealing with tropical field crops, and of everyone generally interested in economic botany.

Charcoal Production and Uses. Ten authors. Northeastern Wood Utilization Council. P. O. Box 1577, New Haven, Conn. Bull. 37. 1952. $2.

The ten articles which compose this booklet represent the papers presented on September 14, 1951, to a conference on Charcoal Production and Uses at Durham, N. H., in cooperation with the University of New Hampshire. Charcoal formerly was produced primarily as a by-product of the wood distillation industry, but the latter has gradually been going out of business because its principal products, chemicals, cannot successfully compete with those made from coal or petroleum. At the same time, however, the demands for charcoal for home burning and from several types of industry continue to increase, so that increased production of the material is needed, and the techniques toward that end are discussed in these papers. Charcoal has thus become a main instead of a by-product, and its production offers one method of utilizing low grade wood.

Formerly the principal outlet for charcoal was in the field of metallurgy, especially in producing high silicon metals and in case hardening steel, brass and copper. These uses are still vital, but a greater percentage of the charcoal produced every year is now going into the manufacture of carbon disulfide. A third important use is in curing shade-grown tobacco. In addition, large amounts are consumed as domestic fuel.